TRENDS IN SOIL ACIDIFICATION IN ALBERTA BASED ON LONG TERM SOIL ACIDIFICATION MONITORING FROM 1981 TO 2010

by

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EXECUTIVE SUMMARY

Long term soil acidification monitoring was initiated by Alberta Environment in 1981 to track potential effects of acidic atmospheric deposition on soils in Alberta. Two sites per year were established for a total of eight sites, with baseline sampling completed in 1984. The sites were established each fall at eight locations in the province, as follows: Fort McMurray, Cold Lake, High Prairie, Bruderheim, Devon, Rocky Mountain House, Esther and Twin Butte. In 2008, a ninth site was added in the Fort Saskatchewan Industrial Heartland area in order to provide a better assessment of acidification impacts from major industrial development and oil sands bitumen upgraders proposed for the region. The original monitoring design entailed sampling every four years, with the design enabling monitoring for a minimum of 44 years. The objective of the program was initially described in a report of the baseline sampling and initial years of monitoring results by Roberts et al. (1989), as follows: "The objective of this program is to detect subtle changes in soil properties indicative of potentially long-term changes in the ability of the soil to sustain plant growth." This report presents the data and statistical analysis of six or seven monitoring events up to 2010.

As stated in the initial report by Roberts et al. (1989), the soil monitoring sites were selected to represent a provincial cross-section of situations thought to reflect worst case scenarios of long range transport of acidic and acidifying substances. The Rocky Mountain House and Twin Butte sites are located downwind from large sour gas processing facilities. The Devon site is in the vicinity of coal fired electrical power generating stations. The Cold Lake site is near heavy oil extraction facilities, and the Bruderheim site, in the Edmonton vicinity, is near a chemical industry area. The Fort Saskatchewan site was added to include a site even closer than the Bruderheim site to the industrial area. The Fort McMurray site is near oil sands mining and extraction facilities. The High Prairie and Esther sites were considered to be representative of air masses entering and leaving the province. These scenarios are essentially the same at the time of the analysis presented within this report (2012); however, some areas have been more dynamic than others, with the Fort McMurray site characterized by an increasing amount of oil extraction activity in the area, and the Cold Lake, Bruderheim, Fort Saskatchewan and Devon sites also seeing increases in activity. The four remaining Alberta sites, however, have been subject to somewhat less or almost no change since inception of monitoring.

The soils at the monitoring sites are moderately acidic to near neutral in pH, with low cation exchange capacities, and as such are considered to be sensitive to the effects of acidic deposition. Every four years, 12 replicate samples have been taken from subplots at each site at depths of 0-2, 2-5, 5-10, 10-15, 15-30, 30-45 and 45-60 cm; the litter layer was also taken from all but the Esther site. Various chemical properties including pH, soluble and exchangeable ions, cation exchange capacity, base saturation percentage, extractable N and P, and total C, N and S were measured.

The four year cycle of sampling was interrupted in 1997 to 1999, when funding was not available to carry out sampling and laboratory analysis. In 2000, the program was re-established and sampling was resumed with application of the same cycle as previously. However, the Fort McMurray site was not sampled in 2000 due to information that both the original sampling site

and an alternate site had been damaged. The original site, located on the east side of the Athabasca River and northeast of Mildred Lake, was subsequently determined to not have been disturbed, and sampling was resumed there in 2004. In addition, in the latest two sampling events, samples from only one of the sub-sites were analyzed, and longer term trends were thus based on one sub-site at each site.

The data from the five to seven sampling events to date were analyzed by application of descriptive statistics, analysis of variance, and linear regression modelling. In addition, simulation of soil chemical changes in relation to acid deposition inputs was carried out using an Alberta Research Council model, the ARC soil acidification model, to examine potential future trends at the long term monitoring sites.

The statistical analysis focussed on three main soil chemical properties considered to be indicative of acidification trends in soils, namely pH, exchangeable base saturation percentage, and the soil solution base cation to aluminum ratio, or a variant of this, the calcium to aluminum ratio. Research in Europe and North America has indicated that changes in each of these soil chemistry parameters can have negative effects on plant growth.

The statistical analyses indicated decreasing trends in pH and base saturation percentage in some of the sites, particularly in the topmost soil layers (0-2 cm, 2-5 cm, and less so in 5-10 cm layers). Comparison of the initial and most recent monitoring data indicated decreases of up to 0.5 pH units in these layers at the Cold Lake, High Prairie, Bruderheim, Devon and Rocky Mountain House sites. In some cases, the changes were only 0.1 or 0.2 units. The Fort McMurray site showed increasing pH in the initial few monitoring events, and then showed a decrease followed by another increase in 2004 and 2008, respectively. Decreasing base saturation percentage was also apparent in the Fort McMurray, Cold Lake, High Prairie, Devon and Bruderheim sites.

Base cation to aluminum ratio and calcium to aluminum ratio showed statistically significant variations within some sites over time, but with the exception of a downward trend at the Bruderheim site, there were no evident overall patterns common to the other sites over time. Both grassland sites (Esther, Twin Butte) had much higher ratios for both Ca:Al and base cation:Al parameters than the forest sites.

Sub-sites in which analytical results were not available for the last two or three years of monitoring tended to display definite trends, and these in general corresponded to trends of the accompanying sub-site with more years of data. As noted above, some parameters did not show consistent trends in the last one or two years of monitoring. As the monitoring program continues, the interpretive value of the sites with fewer years of data will be limited. Based on this observation, it is recommended that analyses be carried out on soil samples from each of the sub-sites at each site, to enable more balanced comparison of results at each site and to provide more rigour to the statistical analysis of differences and trends.

Seven of the nine long term sampling sites are located in forest ecosystems in northern and central Alberta. Most of these showed trends of downward change in acidification parameters over time. Continued monitoring is therefore, recommended for all of these sites.

The Esther and Twin Butte site are located on grassland soils. The Esther site is located on sandy, weakly buffered soils. Although definite trends were not detected in this soil, it is the only site representing weakly buffered grassland soils, and continued monitoring is recommended.

The Twin Butte site is situated in relatively well buffered soils, and no trends were detected in the acidification chemistry of these soils. Consequently, this site is not likely to show changes until several decades have passed. A revised approach to monitoring this site is suggested, with one approach entailing sampling events being carried out over longer intervals, such as every eight or ten years, rather than the current four year cycle.

Application of the ARC acidification model to the monitoring site soils resulted in calculation of very low (<0.1 kmol H^+ ha^{-1} y^{-1}) critical 50 year critical loads for the most poorly buffered soils, namely the Fort McMurray, High Prairie and Bruderheim sites. Very low (<0.1 kmol H^+ ha^{-1} y^{-1}) 100 year critical loads were obtained for the above sites, as well as the Cold Lake site. A 0.2 (<0.1 kmol H^+ ha^{-1} y^{-1}) critical load was derived for the Esther site. The Devon and Rocky Mountain had 50 year critical loads of 1 and 0.9, respectively, and the Twin Butte and Fort Saskatchewan sites each had a critical load of 0.7 kmol H^+ ha^{-1} y^{-1}. These sites had 100 year critical loads of 0.5 kmol H^+ ha^{-1} y^{-1}, except for Fort Saskatchewan which was lower at 0.3 kmol H^+ ha^{-1} y^{-1}. In all of these cases, the model trends over time show very rapid drops in pH, base saturation percentage and base cation:aluminum ratio.

The modelling component of this investigation required the re-analysis of historical samples from the initial monitoring events in the early 1980s. Analyses that were carried out included pH, cation exchange capacity, exchangeable cations, and water soluble ions. There was remarkable agreement between the analyses carried out in 2006 and the results from the 1980s. Continued archiving of samples is thus warranted, should other repeat analyses or new analyses be required in the future.

ANOVA and linear modelling approaches showed significant differences even in instances where there was a 0.1 or 0.2 pH change, or where other parameters showed very small differences. Such small changes are not necessarily biologically significant, and it is therefore important to note these situations in statistical analysis. Both multivariate statistical approaches have limitations. Regression (linear modelling) should be applied mainly as supporting the ANOVA analysis because trends in soil chemical changes are not necessarily linear, as assumed by the linear modelling approach. The analysis of variance appeared to show more definite trends for plots with several years of data as opposed to plots with only three or four years of data. Consideration should be given to analysis of the soil samples from future as well archived samples from previous sampling events. This would enable more balanced comparison of results at each site as well as provide more rigour to the statistical analysis of differences and trends.

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1.0 INTRODUCTION

Acid deposition and its impacts on the environment has been an issue in many areas of the world. In Alberta, the development of sour gas extraction and processing, oil sands development, and expansion of coal-fired power generation facilities through the 1960s and 1970s led to concerns about the potential for acidifying impacts on soils and water bodies in Alberta. Acidifying emissions were already causing environmental problems in eastern Canada.

Alberta Environment, in conjunction with other agencies, implemented the Acid Deposition Research Program (ADRP). Throughout the 1980s, the ADRP undertook major studies on acidifying emissions in Alberta, including the classification of soil sensitivity to acid deposition (Holowaychuk and Fessenden, 1987). They identified 23% of Alberta soils being highly sensitive to acidification, and 31% being classed as having medium sensitivity. Computer simulation models (Abboud and Turchenek, 1990; Turchenek et al., 1987) also predicted potential long-term effects on sensitive soils.

Because soil acidification is a natural process, it is difficult to separate the natural processes from the anthropogenic additions of acidifying emissions. The rate of the change is also influenced by the buffering capacity of the soil, or how resistant the soils are to acidifying effects. Spatial variations in soil types, and short term changes in biological processes make the measurement of these changes very difficult over the short term.

1.1 LTSAM HISTORY

In order to provide quality information about the level and rate of acidifying effects on sensitive soils, Alberta developed a Long-Term Soil Acidification Monitoring (LTSAM) program. The LTSAM program was initiated by staff of the Soil Protection Branch of Alberta Environment in Lethbridge in 1981. The program was designed to provide an early warning of the adverse effects of acidifying emissions on Alberta soils. It was also designed to detect subtle changes in soil chemistries that would have the potential to affect plant growth over a long period of time, while factoring out natural variations. As such, the program was established on the most sensitive soils that could be found in areas likely to be affected by acidifying emissions, or that reflected acidifying emissions coming into or leaving the province.

Initial sampling was undertaken in 1981 at two sites (Rocky Mountain House and Fort McMurray), and two sites were established in each of the following three years (Bruderheim, Cold Lake, Devon, Esther, High Prairie and Twin Butte) until a total of eight sites had been set up and sampled. The sampling program was set up to sample two sites each year on a four year rotational basis, and the program was designed to run for a minimum of 44 years (60 years for the Fort McMurray site) (Figure 1). Intensive industrial development proposed for the Industrial Heartland near Fort Saskatchewan triggered the establishment of a ninth site, situated closer to Fort Saskatchewan.

Figure 1. LTSAM Sampling Sites

1.2 OBJECTIVES

The objectives of the current study are to review and analyze the soil monitoring data collected

since the LTSAM program was initiated. An earlier review had been done in 1989 after two sampling events had occurred (Roberts et al., 1989); however, the data were limited. The current review covers 29 years (1981-2010), comprising six or seven sampling events at each site. This longer monitoring period provides more data for determining trends and utilizing more extensive statistical procedures, as well as testing and validating models. The results of the analysis will also enable a thorough review of the program, the sites, the parameters analyzed for, and potential (or need) for integration with related monitoring programs.

2.0 FIELD AND LABORATORY MATERIALS AND METHODS

2.1 SITE SELECTION

Sites were selected according to criteria that included: proximity to existing sources of acidifying emissions; existence of highly acid sensitive soils; location in undisturbed forest or on native grassland; and, long-term secured access and constraints on future development. Locations on cultivated soils were avoided, as cultural practices such as nitrogen fertilization (which can act as an acidifying agent) can mask the effects of acidifying emissions from atmospheric deposition. The soils at each site are described in Appendix A. Each site was assigned a protective notation through Land Titles, enabling protection from development.

The Bruderheim site is situated downwind of major industrial operations northeast of Edmonton in existence since the 1950's (Figure 1). The site is located in a Natural Area. The Cold Lake site is situated in an area of heavy oil development, also in a provincially protected area. The Devon site is situated downwind of coal fired generating stations near Lake Wabamun, and is on the property of the Devon Botanical Gardens. The Fort McMurray site is located north of Fort McMurray, northeast of the two oil sands mining operations that were operating at the time the program was initiated. The Rocky Mountain House and Twin Butte sites are situated downwind of large sour gas processing facilities. Of the six sites listed so far, all are in forested areas, on predominately sandy soils, with the exception of Twin Butte. This site is located on native grasslands and has a loamy moraine type soil.

High Prairie and Esther were established as regional sites. High Prairie was selected as a monitor of acidifying effects from sources outside of Alberta, although significant oil and gas development has since occurred within Alberta to the west of the site. Esther was selected to monitor the effects of acidifying emissions in air masses leaving the province. Esther is the only other site on native grasslands.

A new site was added to the program in 2008, to provide a better assessment of acidification impacts from major industrial development and oil sands bitumen upgraders proposed for the region. The Bruderheim site was considered to be slightly outside of the potential acidification deposition area, so a site closer to Fort Saskatchewan was added to the program.

2.2 SAMPLING DESIGN

The sampling design for this program was based on a stratified random sampling procedure. Each site had two sub-sites (established to alleviate concerns about loss of a site through vandalism or destruction), and each sub-site (24 m X 24 m) was subdivided into 12 plots (6 m X 8 m) and assigned a letter from A to L. The plots were further subdivided into 12 subplots (2 m X 2 m). The subplots were randomly assigned a number from 1-12, each number reflecting the number of the sampling event. This provides a total of 12 replicates for each sampling event, and 12 sampling events over the course of the program. The detailed layouts for each of the sub-sites are in Appendix B.

Corner posts for the sub-sites were 10 cm diameter fence posts, with metal tags nailed on to label each corner with its directional orientation. Cedar stakes were used to mark the corners of the sub-plots, and were replaced as they deteriorated over the years.

2.3 SAMPLING PROCEDURE

At each monitoring site, the sub-plots within each plot were located for each sampling event (e.g., sub-plot 1 was sampled during the first sampling event, sub-plot 2 during the second event, etc.) within each of the sub-site layouts (Appendix B). At the centre of each sub-plot, a square pit (50 cm X 50 cm) was laid out, and the vegetative growth, including live moss and lichen, was removed and set aside. The LFH horizon was removed by hand with the aid of a stainless steel knife or spatula, and bagged. A pit was then dug to a depth of about 80 cm. Tree roots encountered were removed with pruning shears or axe. The sand and soil removed was set aside on a plastic tarp to avoid impacting adjacent sub-plots with subsurface soils.

Once the walls of the pit were squared off, the mineral horizons were sampled at depths of 0-2, 2-5, 5-10, 10-15, 15-30, 30-45, and 45-60 cm from three sidewalls of the pit with a stainless steel spatula, scoop and tray. In some cases, an abundance of roots precluded sampling one of the sidewalls and a larger area was sampled on two sidewalls instead. The mineral soil removed from the pit was then replaced in the approximate order it was removed, and was topped off by the vegetative growth removed at the beginning of the procedure. Disturbance was minimal, and evidence of the sampling was rarely evident on subsequent sampling trips.

2.4 SAMPLE ANALYSIS

One of the challenges to the continuity of the LTSAM program has been the change in analytical laboratories. Initially, all samples were analyzed at the Soil Protection Branch laboratory in Lethbridge. With the closure of that laboratory in 1994, samples were subsequently analyzed at Norwest Labs in Edmonton in 1995 and 1996. There was a three year hiatus in the program (1997-1999) until funding for the program was re-established by AENV, and samples have been analyzed at Alberta Research Council in Edmonton since 2000.

The same parameters have been measured over the duration of the program; however, in order to keep costs under control, only the LFH, 0-2, 2-5, 5-10, and 10-15 cm depth samples were analyzed from only one of the two sub-sites since 2000. All samples collected at each sampling event are dried, ground to pass a 2 mm sieve, and archived in storage facilities in Edmonton.

Analytical procedures used at the Soil Protection Branch laboratory are outlined in Roberts et al. (1989). Detailed analytical procedures that follow are based upon the procedures used at Alberta Research Council's facility in Edmonton.

2.4.1 Soil pH

Soil pH was measured in $CaCl_2$ using the same methodology in all sampling years, as outlined in Roberts et al. (1989). A 1:2 mixture (soil:0.01 M $CaCl_2$) for mineral samples, and a 1:5 mixture for LFH material, was stirred for 30 minutes, left to settle for 30 min, and then measured with a pH meter after equilibrating the electrodes for 1 min.

2.4.2 Exchangeable Cations and Cation Exchange Capacity

Exchangeable cations and cation exchange capacity (CEC) were determined up to 2000 using the method of Rhoades (1982), as described in Roberts et al. (1989). Soil samples were extracted with non-buffered $BaCl_2$ (1:10 soil:solution ratio). The ions Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{3+}, Mn^{2+} and Al^{3+} were measured on the extract by atomic absorption spectroscopy. The CEC was calculated as the sum of the exchangeable cations:

$$CEC = \Sigma (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{3+}, Mn^{2+}, Al^{3+})$$

where the exchangeable ions are expressed as $cmol_c\ kg^{-1}$ (Hendershot and Duquette, 1986). The base saturation percentage (BSat) was calculated as:

$$BSat = \Sigma (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+})/CEC \times 100$$

In 2000 and subsequent years, the same basic procedure was used, except that soil samples were extracted with a vacuum syringe extractor system and the exchangeable cations were determined by inductively coupled plasma atomic emission spectroscopy.

2.4.3 Soluble Ions

Soil saturated pastes were prepared according to the USDA Soil Salinity Laboratory method (USDA, 1954; Rhoades, 1982); were extracted using a vacuum extractor and the extracts analyzed for pH, electrical conductivity and soluble ions. Soluble ions (Ca, Mg, Na, K, Al, Fe ,Mn, S) were determined in the extracts by inductively coupled plasma atomic emission spectroscopy. Extract pH was measured using a pH meter with a combination electrode. Extract electrical conductivity was measured using a conductivity meter and saturation percentage was calculated from the weights of the soil and added water.

2.4.4 Other Analyses

Chemical analysis of archived soil samples from the initial sampling events at all sites were required to obtain input data for application of the ARC soil acidification model. Archived soil samples from the first sampling event for each plot were retrieved from storage and a composite sample was prepared from equal weights of each replicate. One composite sample was obtained for each sampled horizon of one subplot in each of the eight LTSAM sites. A total of 48 samples were thus obtained and subsequently analyzed for pH ($CaCl_2$), CEC and exchangeable cations using normal ammonium acetate extraction.

Cation exchange capacity (CEC) and exchangeable cations of archived soil samples were determined by extraction with a normal (1 M at pH 7.0) ammonium acetate solution (Holmgren et al., 1977), where NH_4 ions were determined by a Tecator Kjeltec Auto 1030 Analyzer distillation and titration unit and the exchangeable ions (Ca, Mg, Na, K, Al, Fe, Mn) by inductively coupled plasma atomic emission spectroscopy.

2.5 SAMPLING PERIODS

Sampling of two sites, Fort McMurray and Rocky Mountain House, was initiated in 1981, and pairs of other sites were sampled each year thereafter. There is thus a four year cycle in the sampling events. In 1997, funding was not available to carry out sampling and laboratory analysis, with this situation continuing up to and including 1999. In 2000, the program was re-established and sampling was resumed with application of the same cycle as previously. However, the Fort McMurray site was not sampled in 2000 due to information that both the original sampling site and an alternate site had been damaged. The original site, located on the east side of the Athabasca River and northeast of Mildred Lake, was subsequently determined to not have been disturbed, and sampling was resumed there in 2004. The sampling timelines for the eight LTSAM sites are shown in Table 1.

Table 1. Sampling Timelines for LTSAM Sites (1981-2010).

Site[z]	Sampling Period																											
	One				Two				Three				Four							Five					Six				Seven	
	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Fort McMurray[y]																														
Rocky Mountain House																														
Cold Lake																														
Twin Butte																														
High Prairie																	W													
Esther									x											v										
Bruderheim																														
Devon																														
Fort Saskatchewan[u]																														

[z]All sites have paired sub-sites

[y]Fort McMurray site was not sampled in 2000. It was thought that the original site had been damaged, but original site field checked in 2004 and found undamaged so sampling proceeded in 2004.

[x]Draft report issued in 1989

[w]Funding cut in 1997

[v]Program re-established in 2000

[u]Fort Saskatchewan Industrial Heartland Site started in 2008

3.0 EVALUATION APPROACHES AND METHODS

3.1 ACIDIFICATION ATTRIBUTES EXAMINED

The first examination of monitoring trends reported by Roberts et al. (1989) provided descriptive statistics for numerous parameters for both of the initial sampling years, and examined the numerical differences between the two years to determine trends. There were indications of possible acidification in the Twin Butte, Fort McMurray, Cold Lake and Rocky Mountain House sites but not at any other sites

The evaluation herein focuses on soil attributes considered to be the most indicative of acidification effects. Holowaychuk and Fessenden (1987), in assessing the overall sensitivity of Alberta's soils to acidification, recognized that base loss, acidification (pH reduction) and Al solubilization were among the most important soil responses to acidification, these changes possibly leading to secondary impacts such as reduced nutrient availability and altered microbial dynamics. They also recognized that cation exchange capacity and pH were determinants of sensitivity to these changes. Subsequent work in Alberta with respect to assessment of acidification rates (Abboud and Turchenek 1990), and derivation of critical loads (Abboud and Turchenek 1988; Turchenek et al. 1992), followed many aspects of European approaches to assessing acid deposition impacts wherein pH, base saturation percentage, Al concentration (mmol L^{-1}) and Ca:Al ratio were determined to be parameters most closely related to vegetation impacts. More recent literature suggests that the ratio of the combined main soil solution base cations (Ca, Mg, K) to Al may be more indicative of acidification than of only the Ca ion to Al ratio. Consequently, the examination of the LTSAM sites focused on detecting possible trends in four soil chemistry attributes comprising three main acidification parameters (pH, base saturation percentage and base cation:Al ratio), plus the variant of the BC:Al ratio in which only Ca is considered (Ca:Al ratio).

3.2 BASIC STATISTICS

Data selection, conditioning and analysis were conducted with SAS® statistical software; graphs were produced using MS Excel®. Several procedures and modules in SAS were used. The dynamic data exchange module (DDE) was used to input data from Excel® to SAS® for analysis and to export data from SAS® to Excel® for graphing. The SAS® SQL procedure was used to select eligible data for analysis; the SAS® means procedure was used to produce summary statistics. Other SAS® printing and plotting procedures were used to explore the data and search for relationships among soil acidity indicators (not reported in this document).

3.3 MULTIVARIATE STATISTICS

3.3.1 Study Design

The study design was described in terms of sampling design (Section 2.2) and sampling periods in Section 2.5. To reiterate, the monitoring design consists of sites at eight locations around Alberta, two study sub-sites at each location, twelve plots (labelled A...L) within each sub-site, twelve subplots within each plot, and in each sampling year (usually 4 years apart), soil from

each subplot was sampled at up to 7 depths (0-2, 2-5, 5-10, 10-15, 15-30, 30-45, and 45-60 cm). Litter (LFH) samples were also taken but were not included in the analysis. Note that the same depths are sampled in each year, but the actual years when the location-sites were measured differed among location-sites.

This design within each location-site combination is a variant of a split-plot design often applied in agricultural field trials. The main plot blocks are the twelve replicate plots established at each location-site. These main-plot blocks are repeatedly measured at multiple years (the main-plot factor). The sub-plots factor is the depth (up to 7) sampled from each replicate in each year.

3.3.2 Multivariate Analysis

3.3.2.1 Analysis of variance

Analysis of variance (ANOVA) was applied in the statistical examination of monitoring results. In the ANOVA analysis, no assumed pattern of changes among years or among depths is assumed. The hypothesis of interest is that the mean of the variable under consideration does not change across years or across depths. If the design were balanced (i.e., no missing values) with *y* years measured on *d* depths, the ANOVA table would be structured as:

Source	df
Replicates	11
Year	*(y-1)*
Replicate*year	11*(y-1)*
Depth	*(d-1)*
Depth*year	*(y-1)(d-1)*
MSE	*By subtraction*
Total	*12yd-1*

The key assumptions are:

a) the variances of the measurements in each year*depth combination are equal;
b) measurements taken at different sampling points have the same correlation regardless of how apart the sampling occasions are. For example, measurements within a replicate that are 4 years apart have the same correlation as measurements within a replicate that are 8 years apart (this is known as compound symmetry); and,
c) the residuals are normal.

The *Year* effect will measure a common change in the mean across year (averaged over depth levels). The *depth* effect measures a common change in the mean across depths (averaged over years). Finally the *year*depth* interaction term investigates if changes over time are the same for all depths. The two error terms (the *replicate*year* and the MSE terms) measure variation at the main-plot and sub-plot levels. In most situations the variance associated with replicates is much greater than the variance associated with the different depths within the same replicate. This implies that it is usually harder to detect year effects than depth effects.

However, not all depths at a location-site were measured on each sampling occasion. For example, the Bruderheim location was measured on five sampling occasions for the top three

depths, but only on four sampling occasions for the bottom four depths. This is true for 10 of the 16 location-site combinations.

For this reason, two separate analyses were conducted – one for the top three depths (2, 5, and 10 cm) and a parallel analysis for the bottom 4 depths (15, 30, 45, and 60 cm) following the template above.

The above analysis was conducted using *Proc Mixed* of SAS (V9.3).

3.3.2.2 Linear Regression

The ANOVA approach is completely general in the sense that there is no *a priori* pattern to the response expected if the hypothesis of equal means is not tenable. For example, the means could increase, then decrease for a few sampling occasions, and then increase again.

The downside to this generality is that it has reduced power to detect specific trends. For example, if the actual trend over time is a linear reduction in the mean, a regression approach where this linear trend is specifically investigated will have greater power to detect a trend then the ANOVA. However, if the actual trend is not a linear change over time, the regression approach has a reduced power to detect the trend.

When a regression analysis is applied to a complex design such as the above, care must be taken to ensure that the multiple measurements on the same replicate and the multiple depths measured on the same plot are accounted for; i.e., it is not sufficient to simply treat all observations as being independent. The split-plot structure must be used when fitting the linear relationship.

If the design were balanced (i.e., no missing values) with *y* years measured on *d* depths, the ANOVA table would be structured as:

Source	df
Replicates	*11*
Year-linear	*1*
Replicate*year	*12(y-1)-1*
Depth	*(d-1)*
Depth*year	*1(d-1)*
MSE	*By subtraction*
Total	*12yd-1*

The key assumptions are the same as in the ANOVA approach.

The *Year* effect will measure a common *linear* change in the mean across year (averaged over depth levels). The *depth* effect measures a common change in the mean across depths (averaged over years). Finally the *year*depth* interaction term investigates if *linear* changes over time are the same for all depths. The two error terms (the replicate*year and the MSE terms) measure variation at the main-plot and sub-plot levels. In most situations the variance associated with replicates is much greater than the variance associated with the different depths

within the same replicate. This implies it is usually harder to detect year effects than depth effects.

However, not all depths at a location-site were measured at each sampling occasion and two separate analyses were also conducted in the regression analysis paralleling the analyses in the ANOVA approach.

The above analysis was conducted using *Proc Mixed* of SAS (V9.3). It is possible to obtain tests for linear year effects for each depth separately (called slices) without discarding the gain in information from pooling across depths.

ANOVA results were used to detect changes in acidification parameters, with regression data used as supporting evidence only. The response of soils to acidity inputs is not linear, and regression was therefore not considered to be appropriate for the primary analysis; however, where changes occur along a short segment of the overall response curve, the regression approach was considered to provide useful information, especially when combined with another (i.e., ANOVA) approach. As noted previously, there is no pre-supposed pattern of change in applying ANOVA. The regression analysis is used herein mainly to describe a change determined by ANOVA to be significant, as possibly being a trend in either the positive or negative direction.

3.4 ACID DEPOSITION ASSESSMENT

Estimates of regional levels of acid deposition for each of the monitoring sites were determined by the Technology Unit, Environmental Policy Branch, Alberta Environment (WBK & Associates, 2006). Potential acid input (PAI) values, based on 1995 and 2000 emission inventories, are indicated in Table 2.

Table 2. Estimated Potential Acid Input at Monitoring Sites

Site Location	PAI (kmol H^+ ha^{-1} y^{-1})
Fort McMurray	0.12
High Prairie	0.05
Cold Lake	0.11
Bruderheim	0.11
Fort Saskatchewan	0.11
Devon	0.17
Rocky Mountain House	0.09
Esther	0.06
Twin Butte[1]	0.00

The PAI at the Fort McMurray site has also been estimated using site specific data for a monitoring site established by the Terrestrial Environmental Effects Monitoring program of the Wood Buffalo Environmental Association. This site, located within a few hundred metres of the Fort McMurray site, was estimated to have a PAI greater than 0.25 keq H^+ ha^{-1} y^{-1} (Golder Associates Ltd., 2004).

[1] Base cation deposition exceeds acid deposition at Twin Butte.

3.5 ACID DEPOSITION MODELLING

3.5.1 Predictive Acidification Modelling

Numerous models have been developed to examine soil acidification, to predict changes in acidification parameters over time and to derive critical loads. Modelling approaches comprise two main categories referred to as 'steady-state methods' and 'dynamic modelling'. Within each category, there are varying degrees of sophistication ranging from simple calculations to complex mathematical constructs.

Steady-state models calculate deposition levels that avoid harmful effects in ecosystems in steady-state. They are mainly used for calculation of critical loads into the distant future, but they do not calculate the rate of change over time. Two types of steady-state models have been developed for soils. One-layer models consider the soil as a single layer, whereas the multi-layer models consider chemical conditions in different soil layers or horizons. The one-layer Steady State Mass Balance (SSMB) model has been the most commonly applied tool for derivation of critical loads of soils in Europe (UBA 2004).

Dynamic models are a family of more complex models that use various calculations to simulate changes in soil solution or water chemistry due to acid deposition over time. Most dynamic models require somewhat more input data than steady-state models. They have been applied in derivation of critical loads, and are useful in scenario analysis; e.g., for assessing effects of given deposition levels over a selected period of time, and for determining the effects of different emission abatement strategies. The most complex dynamic models are integrated forest-soil models that link soil processes to other processes such as vegetation growth, hydrology and nutrient cycling.

The ARC model, applied herein to examine future trends at the LTSAM sites, is a relatively simple, semi-empirical dynamic model, wherein acidification trends are in part based on soil chemistry relationships determined from readily available data which can be found in soil survey reports and other soil databases.

3.5.2 ARC Model Description

The ARC model simulates mineral soil chemical processes directly related to acidity and acidification of soils, and predicts the associated soil properties of pH, base saturation, solution Al^{3+} concentration and base cation to aluminum (BC:Al) ratio. The ARC model is described in detail in Turchenek and Abboud (1988), Abboud and Turchenek (1990) and Abboud et al (2002). This model is adapted from the Bloom and Grigal (1985) model, with modifications for calculations of acid inputs and acidification processes, method of output of model results, and inclusion of calculations for base cation to aluminum (BC:Al) ratio. These are described in greater detail in the following sections.

3.5.2.1 MODEL INPUTS

The model requires climatic, soil and acid input data with a provision for varying time period for exposure and a varying time increment reporting simulation results.

Climate Data

Data for precipitation and precipitation surplus were applied in the model. Previous applications of the model used a 'precipitation minus potential evapotranspiration' term to determine the amount of precipitation water that percolates beyond the 25 cm layer. This calculation results in a negative value for some climates in Alberta. The precipitation surplus concept provides a more realistic approximation of the amount of water that is actually evaporated or transpired by accounting for episodes of high precipitation and deep moisture percolation. A more detailed description of this concept as applied to soils of the Oil Sands area can be found in Abboud et al. (2002).

Soil Data

Soil data inputs for the ARC model were as follows:

pH – by the water paste method. Where the pH data were determined in a $CaCl_2$ solution (1:2), then the following equation (developed for mineral soils from a correlation of pH values using data from Pauls et al. (1996) was used to transform into a water paste pH:

$$pH_H = 0.94\ pH_C + 0.72 \qquad R^2 = 0.984,\ n = 130 \text{ samples}$$

Cation exchange capacity and exchangeable bases – by the ammonium acetate extraction method.

The input data for soil pH, CEC , and sum of bases were weighted mean values for the whole LFH layer (usually less than 25 cm) and the top 25 cm of air-dried mineral soil. The thickness of the soil horizons and the bulk density were considered in computing the means. The calculations were made as previously documented by Turchenek and Abboud (1988) and Abboud and Turchenek (1990).

Partial pressure of CO_2 – Assumed to be 0.005 atmosphere.

Activity coefficients of monovalent, divalent and trivalent ions – Activity coefficients for each modelled soil horizon were calculated from the mean values for individual members of that series.
The activity coefficients (γ_i) were calculated using the Davies equation (Lindsay, 1979).

$$\text{Log } \gamma_i = -AZ_i^2\ [\{I/(1+I^{0.5})\} - 0.3\ I]$$

Where A = 0.509 for water, Z is ion valence and I is ionic strength in moles L^{-1}

The ionic strengths (I) were calculated from the electrical conductivities of the saturated paste extracts (Lindsay, 1979).

$$I = 0.013\ EC$$

where I is in moles L^{-1} and electrical conductivity (EC) of the saturated paste extracts in dS m^{-1}.

Initial weathering rates (kmol ha^{-1} y^{-1}) for mineral soils – these varied with soil texture as discussed in Abboud et al. (2002) and shown in Table 3 below.

The weathering rate (r) of soil minerals is estimated in the model by the function,

$$r = r_o 10^{-0.5(pH-pHo)}$$

where r_o and pH_o are the initial conditions. The r_o value is based on soil texture as shown in Table 3, and a pH of 5.0 was applied in the equation.

Table 3: Estimated Weathering Rates Suggested for Modeling Soils of varying Textures.

Soil Texture	Weathering Rate in 25 cm Surface Soil Layer (kmol ha^{-1} y^{-1})
Sand	0.07
Loamy Sand	0.10
Sandy Loam	0.15
Loam, Silt Loam	0.25
Clay Loam, Silty Clay Loam, Sandy Clay Loam	0.50
Clay, Silty Clay	1.00

Source: Abboud et al. (2002)

Acid Deposition Data – Application of the model using a range of PAI values is carried out in order to determine critical loads. The loads used in this modelling exercise were 0.05, 0.1, 0.2, 0.3, 0.5, 0.7 and 1.0 keq ha^{-1} y^{-1}. These values were recommended for model application by the Alberta Environment staff and cover existing PAI values and potential extreme future values encountered in the province. The PAI values account for both wet and dry forms of acid deposition.

Time – The model can be executed for any specified length of time, and simulation results can be reported for any specified increment of time within the total simulation period. Predictive soil effects data are especially of interest in terms of the immediate and near future; i.e., the period during which pollutant emissions can be forecast. It is also of interest, from a soil development point of view, to determine soil responses to acid deposition over very long periods of time since changes in soils occur slowly. Three hundred years was selected for the simulation period. This time frame would not obscure the data for interpretation of short-term effects, yet would provide a longer term view of soil changes.

A five year increment of time between reported values in the simulations was selected. This increment assured that sufficient data points were obtained for determining the trends of pH, base saturation, Al^{3+} levels and BC:Al over time.

3.5.3 Model Execution and Data Output

3.5.3.1 Computations

The loss of bases is calculated on an annual basis from,

$$S = I - A - C - W$$

where S is the sum of bases lost, I is the effective acidity in the precipitation plus dryfall (the PAI), A is the acid leached out of the top 25 cm of soil, C is the decrease in bicarbonate weathering due to the decrease in soil solution pH, and W is the base contribution due to weathering. At the end of each year of simulation, a new sum of bases is calculated from the sum for the previous year. New values for pH, Al^{3+} concentration and BC:Al ratio are also calculated from equations relating pH with base saturation, pH with solution Al^{3+} concentration, and pH with BC:Al ratio. A linear function describes the relationship between pH and base saturation percentage of the soil. The functions have been determined previously for mineral soil orders and reported by Abboud and Turchenek (1990) and for LFH layers by Abboud et al. (2002).

3.5.4 Changes to the ARC Model

Several changes were made to the previous ARC model when applied in the Oil Sands area (Abboud et al., 2002). These included the addition of acid interaction with the LFH layer and subsequent leaching to the mineral soil underneath, resulting in a two layer model; and, addition of a new module to calculate the changes in mineral soil BC:Al ratios with changes in soil pH.

3.5.4.1 Base Saturation and pH relationships

The pH-BSat relationships for mineral soils were previously developed as linear equations for each soil order in Alberta (Abboud and Turchenek, 1990). Using the data in the Oil Sands area, Abboud et al. (2002) developed a similar relationship for organic soil horizons (LFH and peat layers). Figure 2 shows a linear relationship between soil pH and BSat with a high R^2 value for both LFH and peat layers.

3.5.4.2 Application as a Two-Layer Model

The ARC model was modified to account for acid interaction with the LFH layer. This modification necessitated the calculation of evapotranspiration and precipitation values for both LFH and mineral layers. The precipitation number for the mineral layer was assumed to be equivalent to the quantity of percolation water value passing through the LFH layer. The acid input is assumed to react with the LFH layers thereby acidifying their soil solutions and contributing the acidity to the mineral layer. Buffering in the LFH layers was assumed to arise from surface reactions (exchange, adsorption and complexation) and solution carbonate reactions. It was considered that there was no weathering in LFH layers.

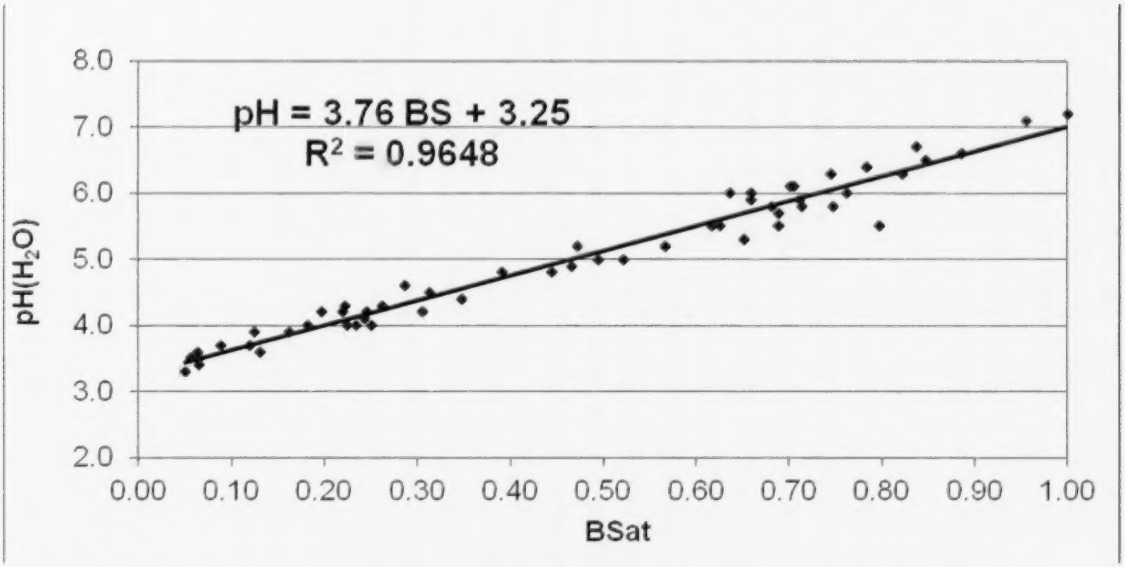

Figure 2. pH - Base Saturation (BSat) Relationship for LFH and Peat Samples (Abboud et al, 2002)

3.5.4.3 Al Solubility

The solubility of Al in the original ARC model was assumed to follow the empirical model of Bloom and Grigal (1985), derived from Minnesota soils data. Recent changes to the ARC model, based on data from southeastern Alberta soils, resulted in the use of a more soluble form of gibbsite as an Al controlling mineral (Turchenek and Abboud, 2001).

During our modelling of soils in the Oil Sands area, the solubility of Al in organic (LFH and peat) horizons was determined using the data collected in that project (Abboud et al., 2002), and in mineral horizons using archived data from a joint Syncrude-ARC project (Pauls et al., 1996).

Figure 3 shows a quadratic relationship between the log of the activity of the free Al ion (Al^{3+}) and the soil solution pH for LFH and peat horizons. This relationship is significant with a high R^2 term. It is likely that a mineral phase is not the only controlling factor for Al solubility; rather, the possibility of complexation with organic ligands must be included.

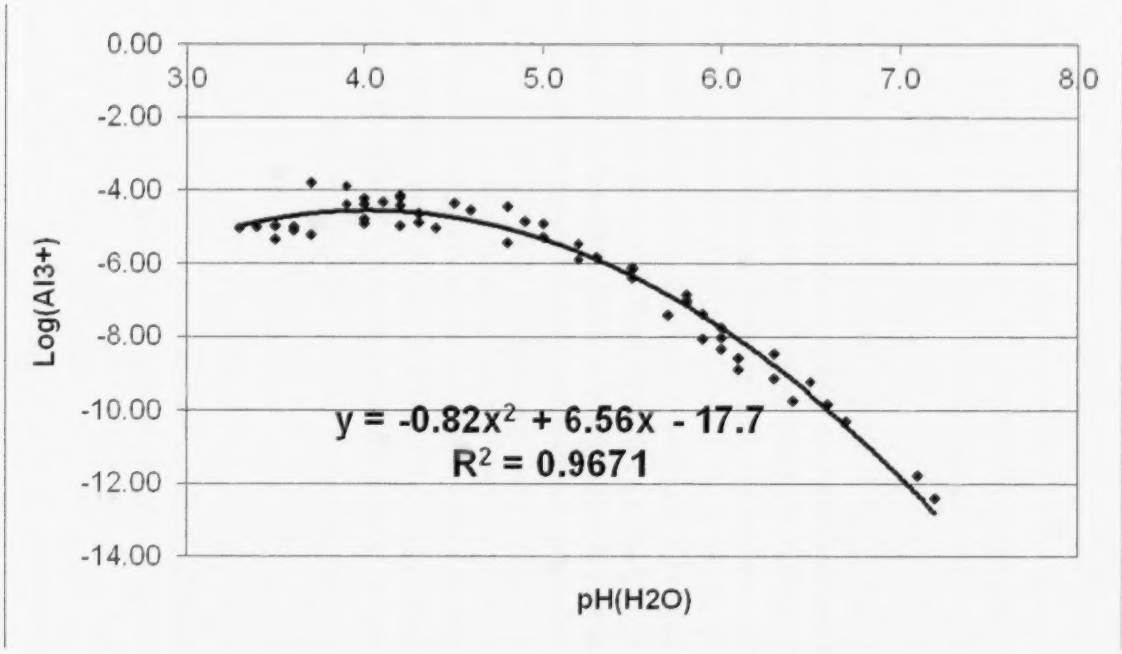

Figure 3. Al Solubility in LFH and Peat Samples

Figure 4 shows the solubility relationship for mineral soils in the upper 25 cm. These covered several soil orders. A linear relationship is evident with a significant R^2 term. This equation is similar in form to the Bloom and Grigal (1985) and Turchenek and Abboud (2001) equations and seem to imply a stronger role for a mineral form controlling Al solubility. The pH coefficient in the equation (2.65) is close to the theoretical value of 3 required for gibbsite to be a controlling mineral, and the constant term (7.93) is close to the theoretical value of 8 assumed for the solubility product of gibbsite. Thus, the possibility of gibbsite controlling Al solubility in these soils is strong, although there is also a likelihood of some influence from the organic matter present in the A horizons and/or from leaching from the LFH layer.

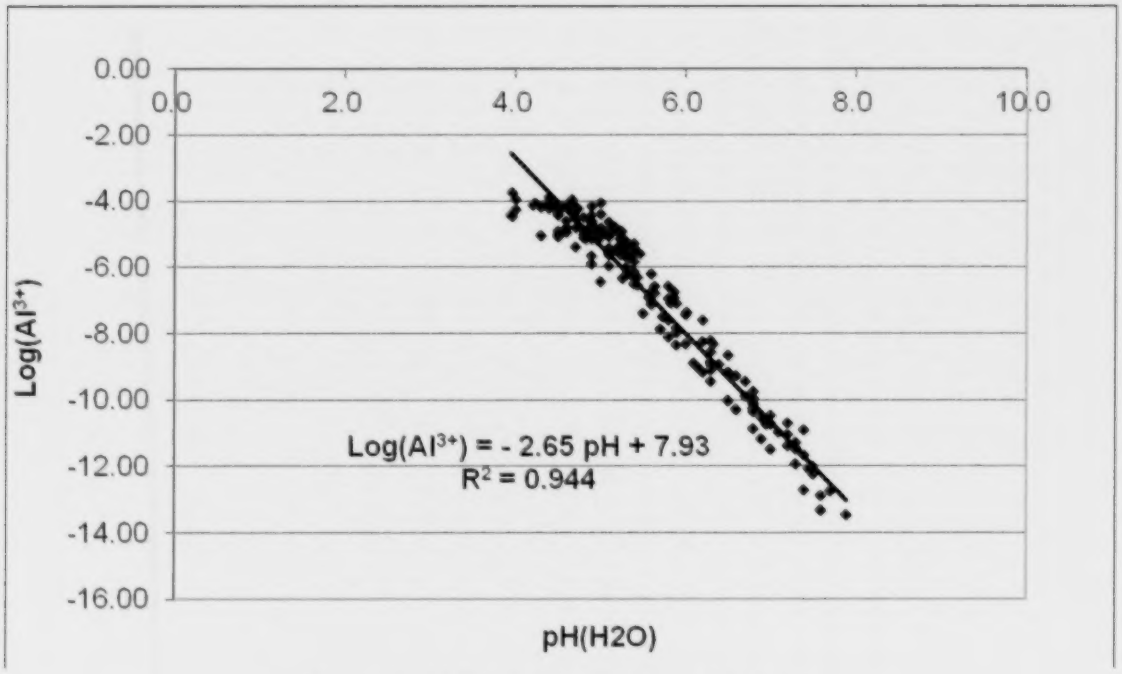

Figure 4. Al Solubility in Mineral Horizons

3.5.4.4 BC:Al Ratios

In mineral soils the relationship between BC:Al ratio and pH shows an exponential relationship with a high R^2 term (Figure 5). This equation shows some scatter which is likely due to the diverse nature of the soil orders, to their mineralogy and texture, and to the influence of weathering and exchange/adsorption processes on both organic and mineral surfaces.

3.5.4.5 Model Execution and Data Outputs

Computations were made for changes in soil properties on an annual basis. Output data for each time interval included: (1) year; (2) pH of soil; (3) acid input; (4) acid output; (5) protonation; (6) change in pH; (7) base saturation; (8) sum of base cations; (9) base cations lost; (10) Al^{3+} concentration in soil solution, and (11) BC:Al ratio. Elements of model output are indicated in Table 4.

The outputs of major interest are the changing values of soil pH, base saturation, and BC:Al during the time period selected. Model data were transferred to EXCEL spreadsheets to facilitate data analysis in terms of critical loads. Simulations were conducted with a desktop computer using the program RS1.

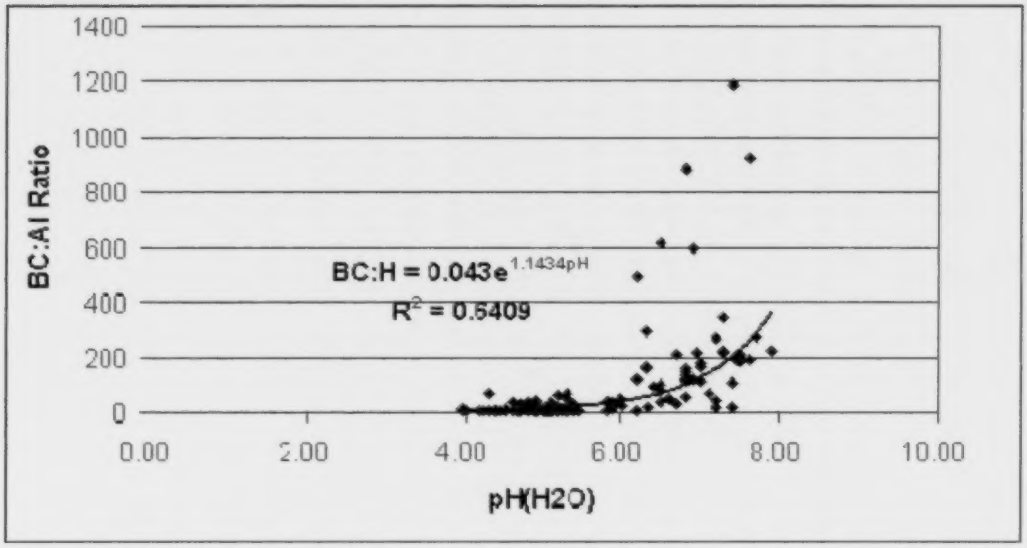

Figure 5. BC:Al Ratio for Mineral Horizons

Table 4. Example of Output from the ARC Model Simulating Processes in a Mineral Soil.

LFH										
Time (years)	pH (H_2O)	Sol. Al (M)	Base Saturation	BC:Al Ratio	Acid In	Acid Out	Protonat.	Bases Lost	Exch. Bases	
					(kmol ha^{-1} y^{-1})					
Mineral										
Time (years)	pH (H_2O)	Sol. Al (M)	Base Saturation	BC:Al Ratio	Acid In	Acid Out	Weathering	Protonat.	Bases Lost	Exch. Bases	Soil Series
					(kmol ha^{-1} y^{-1})						

[2] Abbreviations: Sol. Al – soluble aluminum; BC:Al base cation to aluminum ratio; Protonat. - protonation
$kmol_c$ ha^{-1} – kilomoles of ionic charge per hectare; y^{-1} – per year

3.5.5 Critical Load Determination

3.5.5.1 Critical Load Definition

The term 'critical load' has been defined in Alberta as 'the highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems' (Clean Air Strategic Alliance and Alberta Environment, 1999). The concept of critical loads has been adopted in various countries, especially those of the European Union, as a method for development and implementation of control strategies for air pollutants. The applicability of critical loads of acid deposition in Alberta has been discussed in Maynard (1996) and Schindler (1996). Based upon these two reports, as well as European experience and research carried out in Alberta, critical loads have become the foundation of Alberta's Acid Deposition Management Framework (Clean Air Strategic Alliance and Alberta Environment, 1999). Further discussion of critical load concepts and application can be found in Abboud et al. (2002) and Turchenek and Abboud (2001).

3.5.5.2 Critical Chemical Criteria and Critical Chemical Values

Critical chemical criteria in relation to soil acidification are those soil properties that can be directly affected by acidic inputs, and which in turn could affect other components of the ecosystem. These criteria are chemical parameters such as pH, exchangeable base saturation, aluminum (Al) concentration in soil solution, base cation (BC) concentration in soil solution, and the ratio of BC to Al concentrations. The chemical criterion is chosen to reflect a change in the ecosystem which would lead to damage. Any or all of these can be selected, and critical loads based upon the inputs chosen can be derived.

For each critical chemical criterion, critical chemical values must be established (Sverdrup et al. 1990). Critical chemical values are frequently referred to as thresholds. The criteria applied to soils, the rationale for each selection, and the critical chemical values (thresholds) assigned to each criterion have been discussed in previous acidification modelling studies; a comprehensive study of forest soils in the oil sands region was carried out by Abboud et al. (2002), and a study of predominantly grassland soils was carried out in the Provost-Esther area, Alberta, by Turchenek and Abboud (2001). Critical chemical values applied in those studies are summarized below.

Soil pH

Soil pH is defined as the pH of a solution in equilibrium with soil. Various methods can be used to measure soil pH, as follows:

pH(paste) - a soil sample is made into a paste with distilled water, and the pH is measured using a pH meter with the pH electrode inserted into the paste;

pH($CaCl_2$) (or pH_C) - a soil sample is mixed in 0.01M $CaCl_2$ at a 1:2 soil:solution ratio (w:v), and the pH is measured using a pH meter with the pH electrode dipped into the solution;

pH(H_2O) (or pH_H) - a saturated paste of soil in water is filtered, and the pH of the filtrate is measured using a pH meter with the pH electrode immersed in the solution; and,

pH(solution) - soil solution is extracted in *situ*, and the pH of the solution is measured using a pH meter with the pH electrode immersed in the solution.

The advantages and disadvantages of the above pH determination methods have been discussed in Abboud et al. (2002). The pH_C and pH_H measures are most commonly used in research and reported in the literature, with pH_C readings generally being about 0.5 units lower than pH_H readings. Since different pH methods provide different numerical results, it is important to indicate which measure is used.

Ulrich et al. (1984) suggested that a soil pH_H of 4.0 to 4.2 posed a high risk of damage to forest ecosystems, and that there was some risk at pH_H values greater than 4.2. Low soil pH is typical of forest soils, while grassland soils, in the native condition, are characterized by relatively higher pH. Turchenek and Abboud (2001) suggested a threshold pH_H level of 5.6 for grassland Chernozemic and other soils with organic-rich A horizons (Solonetzic soils, Humic Regosols, Vertisols). This was largely based on research on cropped soils, whereby research on the prairies has shown that crop yields could be affected when soil pH_H levels were in the range of

5.6 to 6.0, or less. It was inferred that a reduction in pH_H below 5.6 could trigger changes in microbiological and plant species composition in native grassland soils; therefore, the suggested critical chemical value for pH_H to be applied in native grasslands dominated by Chernozemic and related soils is pH 5.6 (Turchenek and Abboud, 2001). This is equivalent to a pH_C of about 5.0.

The different critical loads are applicable to the LTSAM soils. Six plots in northern and central Alberta are situated in forest ecosystems with Brunisolic soils. A critical chemical soil pH_H value of 4.0 to 4.2 is suggested for these soils. The plots at Esther and Twin Butte are situated on Chernozemic soils, for which a critical chemical soil pH_H value of 5.6 is suggested.

Calcium to Aluminum (Ca:Al) and Base Cation to Aluminum (BC:Al) Ratios

Aluminum (Al) in soil solution is toxic to vegetation and different threshold levels of Al^{3+} related to plant health have been suggested. Cronan and Grigal (1995) indicated that although total concentration of Al in soil solution might appear to be the most straightforward index of potential Al toxicity to plants, this measure usually fails to be closely related to plant health. Reported Al toxicity thresholds for trees have a wide range, from <40 $\mu mol\ L^{-1}$ to >3,000 $\mu mol\ L^{-1}$. However, toxicity has been shown within a much narrower range in terms of the Ca:Al molar ratio (range of 0.2 to 2.5), and risk thresholds are therefore more appropriately indicated in terms of this latter measure (Table 5). The BC:Al ratio has more recently been applied instead of Ca:Al because of work showing that BC:Al correlates more strongly with plant root or shoot damage than Ca:Al. The term 'BC' in this expression refers to the sum of the molar concentrations of the cations Ca, Mg and K.

Sverdrup and Warfvinge (1993) presented a data compilation from the literature showing response curves of growth of various tree and ground vegetation species in relation to the BC:Al ratio. This was based mainly on growth of species seedlings in nutrient solutions in the laboratory, although some field studies were conducted as well. The BC:Al ratios at which growth of various species was negatively affected ranged widely from 0.3 to 300. The negative effect was considered to occur at the BC:Al ratio where growth was reduced to 80% of normal. The data of Sverdrup and Warfvinge (1993) suggest that of the tree species, aspen is the most sensitive with a critical BC:Al ratio of 6 (Table 6). Conifer species have ratios of 1.5 or less. A number of broad-leaved herbs, grasses and sedges were also listed, with most forest species having ratios less than 6, although some were in the range of 10 to 45, and certain weed species and agronomic grasses had ratios between 100 and 800.

It is clear that there is no single appropriate BC:Al ratio that would be protective of all species. The BC:Al ratio of 1, which is applied to forest soils in Europe, may not be protective of all forest ecosystem types. Further discussion regarding selection of the critical chemical value for BC:Al ratios is presented in Sections 5.3 and 5.4.

Table 5. Critical Chemical Criteria (Indicators) and Critical Chemical Values (Thresholds) of Stress in Forest Ecosystems. [z]

Measurement Endpoint (Critical Chemical Criteria)	Threshold (Critical Chemical Values)
Soil percent base saturation	<15% of effective CEC
Soil solution $Ca:Al_i$ molar ratio	1.0 (50% risk) 0.5 (75% risk) 0.2 (95-100% risk)
Fine root Ca:Al molar ratio	0.2 (50% risk) 0.1 (80% risk)
Foliage (current year) Ca:Al molar ratio	12.5 (50% risk) 6.2 (75% risk)

[z] From Cronan and Grigal (1995).

Table 6. Critical BC:Al Ratios for Various Forest Species. [z]

Plant Species	Common Name	Critical Base Cation:Al Molar Ratio
Picea glauca	White spruce	0.5
Picea mariana	Black spruce	0.8
Abies balsamea	Balsam fir	1.1
Pinus banksiana	Jack pine	1.5
Larix decidua	Larch [y]	2
Betula papyrifera	Paper birch	2
Populus tremuloides	Aspen	6
Salix fragilis	Willow	5
Vaccinium myrtillus	Blueberry	0.2 - 0.6
Vaccinium vitis-idea	Lingon berry	1.2
Vaccinium macrocarpon	Cranberry	1.5
Crocus spp.	Crocus	5
Maianthemum bifolium	May Lily [x]	0.3
Mycorhizza (3 species)	Mycorhizza	0.4
Actinomycetes	Fungi	2
Bacteria *(Various species)*	Bacteria	6

[z] After Sverdrup and Warfvinge (1993).

[y] Not an Alberta native species; data for *Larix laricina* were not provided.

[x] Not an Alberta native species

Base Saturation Percentage

Base saturation percentage refers to the proportion of exchangeable base cations in relation to the total cation exchange capacity. Soil percent base saturation was identified by Cronan and Grigal (1995) and by Miewes et al. (1986) as important in evaluating potential acidification stress on forest ecosystems. While there are various methods of measuring base saturation, the method relevant to threshold limits is based on percent of 'effective cation exchange capacity'. Effective cation exchange capacity (CEC) is defined as the CEC that occurs at field pH, as opposed to CEC measured at a specified pH (i.e., using a pH buffered extractant). Effective

CEC is measured by extraction of exchangeable cations using a neutral, unbuffered saturating solution such as NaCl, KCl, $BaCl_2$ or NH_4Cl. The effective CEC quantifies the number of negatively charged sites with which cations are associated; the major cations in most soils are Ca, Mg, K, Na, Al, Fe, Mn and H. Thus;

CEC = Ca+Mg+K+Na+Al+Fe+Mn+H (expressed as cmoles charge per kg)

Base Sat 1 = (Ca+Mg+K+Na) x 100 / (Ca+Mg+K+Na+Al+Fe+Mn+H)

Ca, Mg, K and Na are categorized as basic cations because the reaction between an exchangeable cation and free H^+ derived from dissociation of water results in generation of hydroxyl (OH^-). Al, Fe and Mn, on the other hand are categorized as acidic cations, as they react and tie up OH^- from H_2O, resulting in release of an equivalent amount H^+ (McBride, 1994).

The measurement of CEC and base saturation according to the above equations rely on measurement of each of the individual cations. An independent measure of CEC can also be obtained. When unbuffered NH_4Cl, or other neutral salt solution, is passed through a soil sample, NH_4^+ displaces the exchangeable cations. The NH_4^+ on the exchange complex is then replaced by Na by passing a NaCl solution through the sample, and the amount of NH_4^+ is measured, the quantity of NH_4^+ being equal to the CEC. Base saturation is then calculated as:

Base Sat 2 = (Ca+Mg+K+Na) x 100 / (CEC)

Base saturation can also be calculated from an independent estimate of the portion of the exchange attributable to acid cations (Al, Fe, Mn and H). This measure is referred to as the Exchangeable Titratable Acidity (ETA). Base saturation is then calculated as:

Base Sat 3 = (Ca+Mg+K+Na) x 100 / (Ca+Mg+K+Na) + ETA

All of the above approaches theoretically provide the same base saturation value, although they seldom do so in practice. Different methods are applied in different institutions and countries. The calculation method for Base Sat 3, is commonly applied in Canada.

For forest ecosystems, threshold base saturation reduction levels based on effective cation exchange capacity have been suggested. A level of 5% (a critical chemical value of 5% base saturation) was suggested by Ulrich et al. (1984), while a reduction to 15% was recommended as a threshold by Cronan and Grigal (1995) on the basis of work by Cronan and Schofield (1990).

Another common approach to determining base saturation percentage involves replacement of exchangeable cations with a buffered salt solution. Two common extractants are ammonium acetate buffered at pH 7, and barium chloride solution buffered at about pH 8.2 with triethanolamine. Mixing a sample of acidic soil with a solution with pH of 7 or more results in dissociation of H^+ ions from functional groups such as -OH and -COOH. When compared to determination of base saturation by neutral salt methods, the buffered methods result in smaller values. Data for soils in Alberta are mostly based on the buffered ammonium acetate method of

CEC and base cation measurement. The application of the ARC acidification model uses CEC and base saturation input data based on the buffered method. Soil samples in the monitoring program were analyzed by the neutral BaCl2 method. Analysis using the buffered ammonium acetate method was therefore required for modelling purposes. Consequently, composite samples from 0-30 cm depths at each site were re-analyzed by the buffered method; details are presented in Appendix E.

Critical criteria for base saturation percentage in grassland soils have been discussed by Turchenek and Abboud (2001). Grassland soils are characterized by relatively high base saturation and pH values. Among the criteria associated with a Chernozemic A horizon are a base saturation greater than 80%, and dominance of calcium (Ca) on the exchange complex (Soil Classification Working Group, 1998). This 80% base saturation level is based on measurement by the 'neutral salt' method. This level was suggested as the threshold level because a soil would deviate from the Chernozemic class of soils if base saturation in the surface soil decreases below 80%.

In summary, suggested critical levels for percent base saturation are 5% or 15% for forest soils; 10% was selected for this study. The critical base saturation level of 80% was used for grassland soils.

3.5.5.3 Critical Load Derivation and Criteria

The ARC model (Turchenek and Abboud, 1988) simulates soil chemical processes directly related to acidity and acidification of soils, and predicts the associated soil properties of pH, base saturation and solution Al^{3+} concentration. Critical chemical criteria such as base cation to aluminum ratio (BC:Al ratio) can be calculated from the soil solution Al values.

Literature-based critical chemical values for pH, exchangeable base saturation percentage and BC:Al ratio were discussed in Section 3.5.4.2. In the Oil sands area of Alberta, the NO_X-SO_2 Management Working Group (NSMWG) of the Cumulative Environmental Management Association (CEMA) examined acidification limits for soils with the objective of establishing a framework for managing acid deposition from industrial activity in order to maintain the chemical characteristics of soils and lakes to avoid adverse effects on ecosystems, plants, or animals (NSMWG, 2004). The NSMWG objective is to limit model-predicted change in either base saturation or the BC:Al ratio in mineral horizons of acid sensitive mineral soils located outside the full footprint of the surface oil sands mines to less than 50% of the difference between pre-industrial values and fixed effects levels. The fixed effects levels applied were 10% for base saturation and a ratio of 2 for BC:Al. The time frame applied in the management framework is 15 to 30 years. Thus, if predictions indicate that management objectives will be exceeded within 15 to 30 years of the present, monitoring, research, and possibly mitigative measures, would be applied.

In establishing this objective, the NSMWG suggested alternatives, such as a change to 75% of the original value of the parameter, in addition to the 50% change. In the initial estimates of critical loads for soils in the region, acidification levels resulting in these thresholds being reached within 50 and 100 years were derived from the model data (Abboud et al., 2002). Fifty years is a relatively short period, and its selection is based on the premise that it is of sufficient

length to enable detection of an actual acidification trend and to initiate measures to counteract the trend. One hundred years is a longer time frame that results in a lower critical load, and it therefore provides a greater level of protection. Both of these time periods were applied in assessing critical loads of the LTSAM soils.

4.0 STATISTICAL ANALYSIS OF MONITORING DATA

4.1 BASIC STATISTICS

The means, standard deviations and coefficients of variation for plots at each of the monitoring sites are presented in the following sections. Data are also presented in graphical form in Appendix C. Analytical data for all sampling events and all sites are provided in Appendix G.

4.2 MULTIVARIATE STATISTICAL ANALYSIS OF ACIDIFICATION TREND

4.2.1 Preliminary Data Screening.

Preliminary screening of the data revealed the presence of several anomalous points. These were included in the analysis unless noted otherwise. For example, values of base-saturations slightly greater than 100% (100-101%) were located in the Esther location in 1995. These were truncated to 100%.

Many values of the Ca:Al ratio were missing (usually caused by a division by 0 for the Al concentration) or were 0 (caused by a value of 0 for the Ca concentration). It is unlikely that either the Al or the Ca concentrations were exactly zero, but rather below the detection limit of the device used to measure these values. For purposes of statistical analysis, values below the detection limit were set to one-half of the difference between the detection limit and zero. The distribution of the F-ratios in the analysis is not simple and must be approximated using one of several popular methods. The Satterthwaite (Steel et al., 1997) approximation was used in these cases.

The Ca:Al and BC:Al ratios are also very sensitive to small values in the denominator, e.g. a value of 0.01 vs 0.02 for the Al concentration will double the ratio. This leads to large variability (in the order of 100+) in these ratios.

Preliminary plots of the variance of the pH, Ca:Al, and BSat values showed that the standard deviation of pH values was independent of the mean, that the standard deviation of the Ca:Al ratio increased with the mean, and the standard deviation of the BSat values decreased with the mean. This suggests that no transformation is needed to analyze the pH and BSat values, and that a logarithmic transformation is suitable for the analysis of the Ca:Al reading.

Furthermore the order of the Ca:Al ratio is arbitrary, e.g. it would be equally valid to analyze the Al:Ca ratio. This also suggests that the log(Ca:Al) ratio could be analyzed as the log(Al:Ca) = -log(Ca:Al) and so similar results will be obtained regardless of the actual ratio used.

Plots of the three analysis variables against each other showed a strong linear relationship between these variables except that BSat reading tended to hit 100% at extremes of the other measurements. This is due to the fact that the exchange sites are filled with "basic" cations (BSat approaches 100%) at higher pH, Ca:Al and BC:Al values. For this reason, BSat values above about 97% should be treated with care, and results are unlikely to be biologically interpretable for these very large BSat values

Both the analysis of variance (ANOVA) and regression approaches were applied to the pH, log(Ca:Al) and the BSat readings. For each variable, tests for trend from the ANOVA and regression approach are provided. These results are summarized in two ways. First, a summary table for each variable is provided which lists the observed p-value for each variable. Second, a series of graphs are provided which repeated the p-value in the upper right part of the graph and show the trend lines from the ANOVA and regression approach.

There is always the danger when many variables are tested in multiple ways that some statistically results will be false positives. For example, if about 100 independent tests were performed when no trend is present with the usual α=0.05 level, then about 5 tests will show a statistically significant trend.

4.2.2 Results of Analysis of Variance

Graphical presentation of pH values, base saturation percentage, BC:Al ratio and Ca:Al ratio at in each of the sampled layers at all plots is presented in Appendix C. Summaries of ANOVA are presented in Tables 7, 8 and 9 below. Results of both descriptive statistics and ANOVA are presented for each of the monitoring sites in the sections that follow. Comments regarding the monitoring parameters in these sections are made below in terms of trends, where significance is indicated in relation to an α level of 0.05. Stated inferences regarding the statistical significance of these trends are supported by a Scheffé multiple-range means test done for each of the four indicator variables to compare yearly variations within horizons at each study location.

Table 7. ANOVA for pH in the Long Term Monitoring Sites.

Site and Sub-Site		DEPTH (cm) [z]						
		0-2	2-5	5-10	10-15	15-30	30-45	45-60
		p value [y]	p value	p value	p value	p value	p value	p value
Fort McMurray	N	<.001	0.980	0.438	0.872	0.732	0.133	0.322
	S	0.597	0.154	0.185	0.558	0.544	0.967	0.593
Cold Lake	E	<.001	0.159	0.925	0.857	0.237	0.645	0.414
	W	0.075	0.335	0.149	0.051	0.284	0.496	0.017
High Prairie	E	<.001	0.007	0.017	0.921	0.714	0.364	0.610
	W	0.108	0.730	0.920	0.896	0.426	0.554	0.755
Bruderheim	E	<.001	0.210	0.175	0.226	0.323	0.280	0.248
	W	0.008	0.014	0.140	0.336	0.509	0.387	0.679
Fort Saskatchewan	N	0.723	0.067	0.014	.	.	.	.
	S	0.290	0.322	.	.	.	.	.
Devon	N	0.003	<.001	0.059	0.065	0.748	0.127	0.042
	S	0.092	0.212	0.368	0.063	0.104	0.389	0.275
Rocky Mountain House	N	0.332	0.030	0.210	0.680	0.629	0.009	0.110
	S	<.001	0.036	0.702	0.890	0.945	0.615	0.238
Esther	N	0.004	0.548	0.030	0.109	0.222	0.022	0.008
	S	<.001	0.769	0.674	0.652	0.804	0.802	0.027
Twin Butte	E	0.151	0.725	0.966	0.776	0.748	0.715	0.378
	W	0.316	0.856	0.597	0.801	0.423	0.080	<.001

[z] Depths (0-2, 2-5, 5-10 cm) and (10-15. 15-30, 30-45 and 45-60 cm) pooled to obtain better estimates of variance components. No correction for multiple comparisons.

[y] p (probability) value; values <0.05 are considered significant.

Table 8. ANOVA for Base Saturation Percentage in the Long Term Monitoring Sites.

Site and Sub-Site		DEPTH (cm) [z]						
		0-2	2-5	5-10	10-15	15-30	30-45	45-60
		p value [y]	p value	p value	p value	p value	p value	p value
Fort McMurray	N	0.011 [y]	0.077	0.021	0.066	0.090	0.177	0.182
	S	0.002	<.001	0.006	0.024	0.287	0.081	0.456
Cold Lake	E	0.019	0.062	<.001	0.402	0.014	0.135	0.122
	W	0.125	0.033	<.001	0.429	0.059	0.346	0.029
High Prairie	E	<.001	0.060	0.404	0.372	0.568	0.733	0.240
	W	0.173	0.349	0.629	0.157	0.860	0.434	0.690
Bruderheim	E	<0.001	0.003	0.231	0.439	0.116	0.229	0.062
	W	0.002	0.006	0.021	<.001	0.025	0.462	0.449
Fort Saskatchewan	N	0.597	0.648	0.595	.	.	.	.
	S	0.085	0.328	.	.	.	.	.
Devon	N	0.132	<.001	0.021	0.060	0.078	0.010	0.413
	S	0.094	0.019	0.410	0.020	0.028	0.001	0.007
Rocky Mountain House	N	0.649	0.174	0.073	0.398	0.548	0.961	0.975
	S	0.027	<.001	0.014	<.001	0.090	0.408	0.223
Esther	N	<0.001	0.025	0.097	0.010	0.127	0.005	<.001
	S	0.007	<.001	<.001	0.021	0.223	0.010	0.059
Twin Butte	E	<.001	<.001	<.001	<0.001	0.514	0.341	0.144
	W	<.001	<.001	<.001	<.001	<.001	<.001	<.001

[z] Depths (0-2, 2-5, 5-10 cm) and (10-15. 15-30, 30-45 and 45-60 cm) pooled to obtain better estimates of variance components. No correction for multiple comparisons.

[y] p (probability) value; values <0.05 are considered significant.

Table 9. ANOVA for log Ca:Al Ratio in the Long Term Monitoring Sites.

Site and Sub-Site		DEPTH (cm) [z]						
		0-2	2-5	5-10	10-15	15-30	30-45	45-60
		p value [y]	p value	p value	p value	p value	p value	p value
Fort McMurray	N	0.005 [y]	<.001	<.001	<.001	<.001	<.001	<.001
	S	0.179	0.085	0.025	0.003	<.001	<.001	<.001
Cold Lake	E	<.001	<.001	<.001	0.187	0.005	0.005	0.001
	W	<.001	<.001	<.001	0.694	0.178	0.911	0.088
High Prairie	E	0.039	<.001	0.017	0.432	0.818	0.025	0.007
	W	0.561	0.752	0.066	0.114	0.004	0.002	0.002
Bruderheim	E	<.001	<.001	0.003	0.004	<.001	<.001	0.004
	W	<.001	<.001	<.001	0.145	0.032	0.030	0.058
Fort Saskatchewan	N	0.373	0.485	0.031	.	.	.	.
	S	0.719	0.646	.	.	.	.	.
Devon	N	0.107	0.245	0.003	0.096	<.001	<.001	<.001
	S	0.051	0.050	0.309	0.096	0.008	<.001	<.001
Rocky Mountain House	N	0.605	0.843	<.001	0.564	0.032	0.011	0.478
	S	0.036	<.001	<.001	0.108	0.197	0.812	0.450
Esther	N	<.001	<.001	<.001	<.001	<.001	0.009	0.330
	S	<.001	<.001	<.001	<.001	<.001	<.001	0.060
Twin Butte	E	<.001	<.001	0.002	0.089	0.655	0.826	0.619
	W	0.002	0.006	0.011	0.147	0.970	0.100	<.001

[z] Depths (0-2, 2-5, 5-10 cm) and (10-15, 15-30, 30-45 and 45-60 cm) pooled to obtain better estimates of variance components. No correction for multiple comparisons.
[y] p (probability) value; values <0.05 are considered significant

Some data observations were made while carrying out the statistical analyses. Some of these pertain to apparent outliers and anomalous values in the data. These are noted below in the individual site summaries. An observation pertaining to several sites concerns a pattern of increasing standard error, indicating a higher degree of variability about the mean, in the latest measurement periods. There are at least three factors other than naturally occurring variability that could singly or in combination have contributed to higher variation:

- there could have been an actual within-block variation between samples;
- there could have been differences in soil collection or analysis techniques between samples within blocks; or
- there could have been data entry errors.

It is recommended that sampling and analysis procedures for the latest analysis period be compared to those for previous periods to ensure consistency.

There are some extreme outliers that significantly affect trends in block statistics. Outliers may be a partial consequence of the same factors listed above that contribute to higher standard errors.

4.2.3 Fort McMurray Site

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the Fort McMurray site are presented in Table 10. Data for all sampled layers are presented for six sampling events in the North sub-site during the period 1981 to 2008. In the last two sampling

events (2004 and 2008), samples below 10 cm were not analyzed. Data for four sampling events are presented for the south sub-site for the period 1981 to 1993.

pH

- pH values in the 0-2 cm layer of the North sub-site ranged between 3.9 and 4.3 among the six sampling events (Table 10). pH values in the 0-2 cm layer of the South sub-site were 4.3 to 4.4 among the four sampling events
- pH differed by up to 0.2 units in the 2-5 and 5-10 cm layers at both sub-sites.
- There was no more than a 0.1 pH unit difference in all layers below the surface 10 cm layer.
- The ANOVA analysis (Table 7 and Appendix C) indicated that difference in pH in the 0-2 cm layer is significant at the North sub-site but not the South sub-site (Table 10). This is likely related to more observation points (two additional years analyzed) as compared to the South sub-site.
- The pH trend in the 0-2 cm layer of the North sub-site was initially upward; it then decreased in 2004, but increased to previous levels in 2008.

Base Saturation

- Base saturation values range from 43 to 65% in the upper three layers and 42 to 78% in lower layers. The data are characterized by wide ranges at most depths in both of the sites.
- In both the North and South sub-sites, average base saturation decreased between 1981 and 1993 in the 0-2, 2-5 and 5-10 cm layers by up to 17%. Decrease in these layers occurred until 1993, and base saturation than increased in the 2004 and 2008.
- Decrease in base saturation percentage also occurred between 1981 and 1993 in the 10-15 and 15-30 cm layers of the north sub-site, but not the south sub-site.
- ANOVA results (Table 8 and Appendix C) indicated statistical significance in the differences in the 0-2 and 5-10 cm layers of the North sub-site, with 2-5 and 10-15 cm layers having alpha values approaching 0.05. ANOVA results for the south sub-site were similar.
- Trends in the 0-2, 2-5 and 5-10 cm layers at the North sub-site consisted of base saturation decreases between the first and fourth monitoring events (1981 to 1993), and then increases in 2004 and 2006. The South sub-site data, consisting of only the first four sampling events, also showed downward trends for these layers.
- The base saturation values are characterized by wide ranges at most depths in both of the sub-sites. Significant differences occur in upper layers, but the trends are not uniform.

Ca:Al and BC:Al Ratios

- Ca:Al ratios were very low in soil layers to 30 cm, ranging from <1 to about 4, in both North and South sub-sites. The Ca:Al ratios are also low in 30-45 and 45-60 cm layers, although there are some higher values up to about 6.
- A decreasing trend in Ca:Al occurred between 1981 and 1993 in all layers .
- ANOVA (Table 9 and Appendix C) indicated differences in Ca:Al to be significant in all layers, except the 0-2 and 2-5 cm layers of the South sub-site.
- An increasing trend in the ratio occurred in the last two sampling events (2004 and 2008).
- The descriptive statistics (Table 10) indicate that the BC:Al ratio trends are similar to Ca:Al.

Table 10. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Fort McMurray Site.

pH ($CaCl_2$) – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year	N	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	4.1	0.2	5.4	4.5	0.3	5.8	4.4	0.2	3.9	4.6	0.2	5.0	4.8	0.2	3.5	5.0	0.1	2.8	5.1	0.1	2.9
1985	12	4.2	0.2	4.5	4.4	0.2	4.1	4.4	0.1	2.5	4.5	0.1	2.2	4.8	0.2	4.8	4.9	0.1	2.2	5.0	0.1	2.8
1989	12	4.3	0.3	6.1	4.5	0.3	6.7	4.5	0.1	2.9	4.5	0.1	2.0	4.8	0.1	2.9	4.9	0.2	3.5	5.0	0.1	2.8
1993	12	4.3	0.4	9.2	4.4	0.3	7.0	4.5	0.2	5.6	4.5	0.2	4.0	4.8	0.2	3.5	5.0	0.1	2.0	5.1	0.1	2.4
2004	12	3.9	0.2	6.1	4.4	0.2	5.4	4.6	0.3	5.9	-	-	-	-	-	-	-	-	-	-	-	-
2008	12	4.2	0.1	3.3	4.4	0.2	3.6	4.5	0.2	4.2	-	-	-	-	-	-	-	-	-	-	-	-

pH ($CaCl_2$) – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	4.3	0.3	6.6	4.6	0.2	5.4	4.6	0.1	3.1	4.6	0.1	2.2	4.8	0.1	2.1	5.0	0.1	2.8	5.0	0.2	4.4
1985	12	4.3	0.2	5.1	4.7	0.2	5.3	4.7	0.2	4.3	4.7	0.1	3.0	4.9	0.2	3.3	5.0	0.2	3.6	5.0	0.2	4.4
1989	12	4.3	0.22	5.8	4.6	0.2	3.9	4.5	0.1	2.9	4.7	0.2	3.7	4.8	0.3	6.0	5.0	0.2	3.4	5.1	0.2	2.9
1993	12	4.4	0.2	4.3	4.5	0.2	4.0	4.5	0.2	3.5	4.6	0.1	3.0	4.9	0.1	2.7	5.0	0.2	3.2	5.1	0.1	1.8
2004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Base Saturation Percentage – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	60	13	22	57	21	38	52	14	27	53	14	26	65	10	15	73	9	13	79	5	6
1985	12	54	5	10	52	8	15	51	6	12	51	7	14	62	14	22	68	9	14	70	13	18
1989	12	46	11	24	46	14	31	44	11	24	45	10	23	56	12	21	63	13	21	72	15	21
1993	12	46	14	31	44	17	38	43	14	33	42	12	29	56	13	23	68	9	13	73	10	14
2004	12	51	9	18	49	12	24	53	14	27	-	-	-	-	-	-	-	-	-	-	-	-
2008	12	54	5	9	51	8	16	56	12	21	-	-	-	-	-	-	-	-	-	-	-	-

Base Saturation Percentage – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	61	10	17	64	8	12	61	8	13	54	8	15	58	9	15	76	8	10	75	10	14
1989	12	59	13	22	65	14	22	63	12	19	59	10	17	62	13	20	68	14	21	77	8	11
1993	12	50	12	25	56	15	26	53	14	27	51	14	28	63	16	26	78	9	12	82	8	10
1993	12	44	13	29	47	14	31	48	14	30	47	13	27	56	12	21	72	10	14	77	8	10

Table 10. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Fort McMurray Site (concluded)

Ca:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	1.5	0.7	48	2.3	1.9	81	2.7	1.0	36	4.2	2.6	62	5.7	3.7	65	3.6	1.2	33	3.6	1.7	46
1985	12	1.6	0.4	28	1.9	0.6	30	2.1	0.3	12	2.8	0.7	26	4.0	1.4	35	2.9	1.0	33	2.2	0.6	29
1989	12	1.0	0.4	39	1.4	0.6	44	1.5	0.4	26	1.9	0.6	31	2.0	0.5	27	1.4	0.6	41	1.1	0.4	38
2004	12	0.9	0.3	31	1.1	0.7	61	2.0	1.9	93	-	-	-	-	-	-	-	-	-	-	-	-
2008	12	1.2	0.5	44	1.2	0.4	34	1.5	0.8	50	-	-	-	-	-	-	-	-	-	-	-	-

Ca:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	1.6	0.6	36	2.6	1.8	69	3.0	0.8	28	4.0	1.1	28	6.3	3.7	59	6.1	4.7	78	4.7	1.6	35
1985	12	1.6	0.6	36	2.5	1.0	39	2.7	0.6	23	3.0	0.8	27	4.0	1.2	31	2.5	0.9	36	2.6	1.2	44
1989	12	1.2	0.4	31	1.8	0.7	38	2.0	0.6	28	2.3	0.6	24	3.0	0.9	30	1.2	0.5	42	0.8	0.3	32

Base Cation:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	3.3	1.2	37	4.4	2.5	56	5.6	2.6	47	7.8	4.7	60	10.8	6.3	58	7.6	2.9	38	8.6	3.6	42
1985	12	3.5	0.8	23	3.9	0.9	24	4.0	0.5	13	5.4	1.6	30	6.9	3.0	43	5.4	1.6	30	4.8	1.2	26
1989	12	2.6	0.6	22	3.3	0.8	24	3.5	0.6	18	4.1	0.8	21	3.9	0.7	19	2.9	0.8	28	2.6	0.9	35
2004	12	3.2	0.6	19	3.9	1.44	35	6.9	6.3	90	-	-	-	-	-	-	-	-	-	-	-	-
2008	12	3.2	1.1	36	3.4	1.0	30	4.4	1.4	31	-	-	-	-	-	-	-	-	-	-	-	-

Base Cation:Al Ratio – South Sub-Site

Depth (cm)	0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	3.3	1.2	36.	4.7	2.4	51	5.4	1.1	21	7.1	1.6	22	11.2	6.8	61	13.6	13.5	103	9.8	3.8	40
1985	3.2	0.9	28	4.5	1.43	32	5.0	1.0	20	5.4	1.1	21	6.9	2.0	29	4.9	1.7	34	5.7	2.1	37
1989	2.8	0.6	21	3.9	1.3	33	4.1	1.2	30	4.6	1.1	23	5.5	1.6	29	2.7	0.9	34	2.2	0.7	30

4.2.4 Cold Lake Site

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the Cold Lake site are presented in Table 11. Data for all sampled layers are presented for four sampling events from 1982 to 1990. No analyses were completed for samples below 10 cm depth from 2001 to 2009, and no layers from the West Sub-site were analyzed in the last two years.

pH

- pH in the East sub-site decreased between 1982 and 2009 by about 0.5 units in the 0-2 cm layer, by 0.3 units in the 2-5 cm layer, and 0.1 unit in the 5-10 cm layer; pH in the West sub-site decreased between 1982 and 2001 by about 0.2 unit in the 0-2 cm layer, remained the same in the 2-5 layer, and increased 0.2 units in the 5-10 cm layer.
- The East sub-site pH decreased every year except for a 0.1 unit increase in 2005; the West site increased between the first and second monitoring years, but otherwise decreased.
- ANOVA (Table 7 and Appendix C) indicated that the pH difference in the 0-2 layer of the East sub-site, but not the West sub-site, was significant. Linear modelling suggested that most of the change in the 0-2 cm layer occurred as a downward trend in both the East and West sub-sites. A significant difference with an overall upward trend was detected in the 10-15 cm layer of the West sub-site. A significant difference was detected in the 45-60 layer of the West sub-site, but the overall trend was horizontal.

Base Saturation Percentage

- In the East sub-site, base saturation in the 0-2 cm layer decreased about 10% between 1982 and 2009; a decrease of 7% occurred in the West sub-site between 1982 and 2001. These changes were significant according to ANOVA (Table 8 and Appendix C) in the east sub-site, but not the West sub-site.
- The base saturation of the 2-5 cm layer decreased by 10% in the East sub-site, but with variation over the sampling period, the difference was not significant ($p=0.062$). Similarly, differences in the base saturation of the 2-5 cm layer in the West sub-site were significant over the 1982 to 2001, but the trend consisted of a decrease and then an increase.
- Both the East and West sub-sites had significant differences in base saturation values of the 5-10 cm layer, but trends consisted of an initial decrease and then an increase.
- Base saturation values in deeper layers were mainly greater than 60% (range 54-93%). Relatively fine textured material occurs at depths just below 60 cm at this site, and this difference in material may influence the results, resulting in high variability.

Ca:Al and BC:Al Ratios

- Ca:Al ratios ranged from 4 to 28 in the 0-2 cm layer of the East sub-sites, with the highest value in 2005. At the West sub-site, the range was 4 to 16 over the 1982 to 2001 period.
- The BC:Al ratio showed trends similar to Ca:Al.
- ANOVA (Table 9 and Appendix C) showed significance in changes in all but the 10-15 cm layer in the East sub-site, and in the 0-2, 2-5 and 5-10 cm layers of the West sub-site.
- Trends in the 0-2, 2-5 and 5-10 cm layers were generally downward, then upward, and then downward again in the 2005 and 2009 sampling years (with the exception of the 2005 spike in the East 0-2 cm layer.

Table 11. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Cold Lake Site.

pH (CaCl2) – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	4.9	0.4	7.8	4.8	0.4	8.2	4.7	0.3	7.3	4.7	0.3	6.6	5.0	0.3	5.7	5.2	0.2	4.7	5.3	0.2	3.8
1986	12	4.9	0.3	6.6	4.8	0.3	6.0	4.7	0.2	4.9	4.7	0.2	3.6	5.0	0.2	3.8	5.2	0.2	3.8	5.3	0.2	3.0
1990	12	4.7	0.2	4.9	4.6	0.3	5.9	4.5	0.2	5.3	4.7	0.2	4.6	4.9	0.2	4.3	5.1	0.1	2.4	5.2	0.1	2.1
1994	12	4.7	0.3	5.3	4.6	0.2	4.5	4.6	0.2	4.8	4.7	0.2	3.6	5.0	0.3	5.2	5.2	0.2	4.4	5.3	0.2	3.8
2001	12	4.5	0.2	5.1	4.6	0.2	4.3	4.6	0.2	4.4	.	.	-	.	.	-	.	.	-	.	.	-
2005	12	4.6	0.4	9.0	4.6	0.4	8.2	4.6	0.2	3.7	.	.	-	.	.	-	.	.	-	.	.	-
2009	12	4.4	0.3	7.8	4.5	0.3	6.0	4.6	0.2	4.1	.	.	-	.	.	-	.	.	-	.	.	-

pH (CaCl2) – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	4.7	0.4	7.8	4.5	0.4	8.0	4.2	0.3	7.8	4.3	0.2	5.9	4.7	0.2	3.6	5.0	0.2	4.0	5.2	0.1	2.5
1986	12	4.9	0.4	7.6	4.7	0.4	7.9	4.5	0.3	7.5	4.5	0.2	4.9	4.8	0.2	4.0	5.1	0.2	3.5	5.3	0.2	3.8
1990	12	4.6	0.3	7.0	4.4	0.3	6.5	4.3	0.2	4.6	4.4	0.2	3.9	4.8	0.2	4.6	5.0	0.2	4.8	5.0	0.3	6.6
1994	12	4.6	0.4	7.8	4.5	0.3	7.1	4.4	0.2	5.3	4.4	0.2	5.6	4.8	0.2	3.1	5.0	0.2	5.4	5.2	0.2	4.2
2001	12	4.5	0.3	5.9	4.5	0.3	7.5	4.4	0.19	4.3	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	94	4	4	90	6	6	82	11	13.9	74	15	20	77	14	18	86	8	9	90	4	4
1986	12	93	3	3	85	8	9	74	10	13.1	70	14	19	71	11	15	78	10	12	83	7	8
1990	12	89	8	9	81	10	13	69	14	20	68	13	20	67	16	23	84	6	8	90	6	7
1994	12	92	5	6	85	8	9	79	9	12	74	8	10	79	10	12	86	6	6	92	3	4
2001	12	87	5	6	85	6	7	84	7	8.3	.	.	-	.	.	-	.	.	-	.	.	-
2005	12	89	7	8	89	6	7	88	5	5.9	.	.	-	.	.	-	.	.	-	.	.	-
2009	12	84	12	14	83	11	13	83	8	10	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	94	2	2	86	6	6	68	13	19	56	113	23	67	11.8	18	86	7	8	92	5	6
1986	12	90	4	4	83	6	7	71	10	13	61	12	19	62	11.8	19	79	8	10	82	13	16
1990	12	87	7	8	78	11	14	64	12	19	54	11	20	72	11.7	16	84	8	10	86	19	22
1994	12	88	6	7	80	8	10	68	9	14	57	9	15	72	10.3	14	85	9	10	93	4	4
2001	12	87	6	6	86	7	8	84	5	6	.	.	-	.	.	-	.	.	-	.	.	-

Table 11. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Cold Lake Site (concluded)

Ca:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	20	23	-	7	7	110	4	3	96	3	2	65	3	2	50	2	2	66	2	1	73
1986	12	6	3	45	3	1	50	2	1	39	2	1	38	2	1	39	1	1	57	1	1	81
1990	12	4	1	29	2	1	34	2	1	34	2	1	43	2	1	27	2	0	24	1	0	25
2001	12	10	4	36	9	3	36	6	4	64	.	.	-	.	.	-	.	.	-	.	.	-
2005	12	28	34	121	9	7	76	4	2	59	.	.	-	.	.	-	.	.	-	.	.	-
2009	12	5	2	50	3	2	53	2	2	104	.	.	-	.	.	-	.	.	-	.	.	-

Ca:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	16	17	106	4	2	60	2	1	58	1	1	36	1	1	33	1	1	39	1	1	51
1986	12	6	3	47	3	1	37	2	1	39	1	0	26	1	1	51	1	1	57	1	1	65
1990	12	4	1	33	2	1	32	1	0	22	1	0	14	2	0	17	1	0	21	1	0	49
2001	12	13	8	63	10	9	85	5	2	50	.	.	-	.	.	-	.	.	-	.	.	-

Base Cation:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	38	46	119	13	13	105	7	7	94	6	3	53	7	2	34	6	3	44	5	3	49
1986	12	11	5	46	5	3	49	4	2	42	4	2	40	4	1	27	3	1	40	3	2	55
1990	12	8	2	29	5	2	31	4	1	23	5	2	30	5	1	16	5	1	17	4	1	26
2001	12	24	8	32	21	7	34	15	8	54	.	.	-	.	.	-	.	.	-	.	.	-
2005	12	48	52	108	17	12	71	7	4	54	.	.	-	.	.	-	.	.	-	.	.	-
2009	12	12	5	47	8	3	40	4	3	78	.	.	-	.	.	-	.	.	-	.	.	-

Base Cation:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	31	30	98	8	4	49	4	2	46	4	1	28	5	2	29	5	2	39	4	2	37
1986	12	12	5	43	6	2	35	4	1	33	3	1	21	4	1	28	4	2	38	4	2	41
1990	12	9	3	30	5	1	24	3	1	17	4	1	22	5	1	19	4	1	20	3	1	42
2001	12	28	18	63	26	22	85	14	7	48	.	.	-	.	.	-	.	.	-	.	.	-

4.2.5 High Prairie Site

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the High Prairie site are presented in Table 12. Data for all sampled layers are presented for four sampling events from 1983 to 1995. No analyses were completed for samples below 10 cm depth from 2002 to 2010, and no layers from the West Sub-site were analyzed in the last three years.

pH

- pH in the East sub-site differed among years by 0.5 units, with the last year (2010) 0.2 units lower than the initial year. The maximum difference in the West sub-site was 0.2 units over the 1983 to 1995 period.
- pH in the 2-5 cm layer differed by 0.3 units in the East sub-site, and 0.1 units in the west sub-site; in the 5-10 layer, differences were similarly low.
- ANOVA (Table 7 and Appendix C) indicated that the differences among years in the three upper layers were significant in the West sub-site, but not the East sub-site. The larger number of sampling events in the East sub-site is a likely factor in the difference.
- The pH trend consisted of an increase initially, followed by a decrease, and then an increase in the last three sampling events.

Base Saturation Percentage

- Base saturation values are relatively high, mainly above 80% in most soil layers. Some layers are characterized by high variability.
- A significant difference was indicated by ANOVA in the 0-2 cm layer of the East sub-site, but not in any other layer or in the West sub-site (Table 8 and Appendix C).
- The trend in the East sub-site 0-2 cm layer was generally downward, with a difference of 10% between the initial and last monitoring events.
- As with pH, significance was different at the two sub-sites. As indicated above, the additional sampling events at the East sub-site likely influence the significance.

Ca:Al and BC:Al Ratios

- The East sub-site Ca:Al ratios in the 0-2, 2-5 and 5-10 cm layers decreased to 2002 and then increased in the 2006 and 2010 sampling events.
- ANOVA (Table 9 and Appendix C) indicated that the differences in Ca:Al values were significant; however, initial and final sampling year values were somewhat similar.
- The Ca:Al ratios were determined only in 1983, 1987 and 1991 at the West sub-site. Both small increases and small decreases were observed in all layers at this sub-site. According to the ANOVA these differences were not significant.
- ANOVA indicated significant differences in the three lowermost layers of the West sub-site and the two lowermost layers in the East sub-site. These differences mainly reflected increases over time.
- The BC:Al ratio showed trends similar to those for Ca:Al ratios.

Table 12. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the High Prairie Site.

pH ($CaCl_2$) – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	5.0	0.2	4.0	5.2	0.2	3.3	5.1	0.2	3.3	5.0	0.2	3.4	4.9	0.2	5.1	4.9	0.2	4.7	5.0	0.2	4.4
1987	12	5.2	0.2	4.8	5.3	0.3	5.1	5.2	0.2	3.7	5.0	0.2	3.4	4.9	0.2	3.2	5.0	0.2	4.2	5.0	0.2	4.6
1991	12	4.9	0.2	4.9	5.1	0.2	4.3	5.1	0.2	4.1	5.0	0.2	4.2	4.9	0.2	4.9	4.9	0.2	4.5	5.0	0.2	4.4
1995	12	4.7	0.2	5.3	5.0	0.3	5.4	5.0	0.2	3.6	5.0	0.2	3.6	4.9	0.3	6.1	5.0	0.2	5.0	5.1	0.2	3.9
2002	12	4.7	0.2	4.4	5.0	0.2	5.0	4.8	0.2	4.1	.	.	-	.	.	-	.	.	-	.	.	-
2006	12	4.8	0.4	7.3	5.1	0.2	5.0	5.0	0.2	3.2	.	.	-	.	.	-	.	.	-	.	.	-
2010	12	4.8	0.2	5.2	5.1	0.2	4.1	5.2	0.2	4.3	.	.	-	.	.	-	.	.	-	.	.	-

pH ($CaCl_2$) – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	4.8	0.3	6.2	5.1	0.3	5.7	5.0	0.3	6.2	5.0	0.3	6.4	5.0	0.4	7.3	5.0	0.2	4.8	5.2	0.3	5.0
1987	12	5.1	0.2	3.9	5.2	0.2	4.5	5.0	0.3	5.4	5.0	0.2	4.8	5.0	0.2	4.6	5.1	0.2	4.2	5.2	0.2	4.6
1991	12	5.0	0.3	5.6	5.2	0.3	5.4	5.1	0.3	5.5	5.1	0.3	5.5	5.1	0.2	3.5	5.2	0.2	3.7	5.3	0.2	3.4
1995	12	4.9	0.2	4.9	5.1	0.3	5.9	5.1	0.33	6.5	5.0	0.3	6.2	5.1	0.3	5.3	5.1	0.2	4.5	5.2	0.2	4.6

Base Saturation Percentage – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	88	4	4	90	5	5	86	5	5	82	7	8	79	15	19	82	8	10	84	7	8
1987	12	93	5	6	92	6	6	90	6	7	86	7	8	81	9	11	81	10	13	84	10	12
1991	12	80	10	12	86	5	6	84	5	6	81	7	9	76	12	16	80	12	15	86	6	7
1995	12	85	6	8	87	7	9	86	5	6	85	6	7	79	18	23	83	11	13	90	6	7
2002	12	79	11	15	83	11	13	83	9	11	.	.	-	.	.	-	.	.	-	.	.	-
2006	12	80	14	17	83	13	16	86	13	15	.	.	-	.	.	-	.	.	-	.	.	-
2010	12	79	7	9	86	6	7	89	4	5	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	84	9	10	86	8	10	84	9	11	82	12	15	85	10	12	90	6	7	93	5	5
1987	12	92	4	5	92	5	5	88	9	11	88	8	10	88	10	11	92	5	5	95	3	3
1991	12	87	7	8	87	7	8	86	7	8	83	8	10	86	5	6	87	5	6	92	4	4
1995	12	87	8	9	86	12	14	84	13	16	85	11	13	87	9	10	91	6	7	94	5	5

Table 12. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the High Prairie Site (concluded)

Ca:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	6	2	30	10	3	32	7	4	55	5	1	27	3	1	29	2	1	61	3	2	78
1987	12	7	5	63	7	3	47	5	1	31	4	1	35	3	1	29	2	1	31	2	1	37
1991	12	5	3	70	6	3	48	5	2	36	4	1	35	3	1	34	3	1	34	3	1	46
2002	12	4	1	30	4	2	42	3	1	43	.	.	-	.	.	-	.	.	-	.	.	-
2006	12	5	3	63	7	5	65	4	2	46	.	.	-	.	.	-	.	.	-	.	.	-
2010	12	6	3	56	13	10	81	7	6	92	.	.	-	.	.	-	.	.	-	.	.	-

Ca:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	5	3	59	7	3	45	7	4	65	4	3	60	4	2	39	3	1	42	2	1	62
1987	12	6	3	47	6	2	29	4	1	31	3	1	30	3	1	30	2	1	41	2	1	41
1991	12	6	4	69	6	3	51	5	2	30	5	1	22	4	1	22	4	1	16	3	1	22

Base Cation:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	10	3	28	15	4	25	11	6	53	7	2	25	5	1	24	5	2	47	6	4	69
1987	12	11	6	56	10	4	43	7	2	26	6	2	34	5	1	28	3	1	30	3	1	30
1991	12	8	5	61	10	4	42	8	3	31	7	2	30	6	2	30	6	2	36	6	3	45
2002	12	7	2	26	8	3	41	7	2	36	.	.	-	.	.	-	.	.	-	.	.	-
2006	12	10	5	54	12	7	58	7	3	46	.	.	-	.	.	-	.	.	-	.	.	-
2010	12	11	6	51	22	16	71	12	10	80	.	.	-	.	.	-	.	.	-	.	.	-

Base Cation:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	9	5	59	11	5	44	10	6	56	7	4	59	7	2	30	5	2	35	5	3	62
1987	12	10	4	42	8	2	27	6	2	28	5	1	28	4	1	24	4	1	38	4	1	32
1991	12	11	7	66	11	5	49	9	3	32	8	2	21	8	2	23	7	1	17	6	1	22

4.2.6 Bruderheim Site

The Bruderheim site was affected by fire in 1998. The damage was minimal and subsequent analysis focused on the west subsite, which appeared to be the least impacted. The site was severely damaged by fire in 2009, a factor that will have to be considered when evaluating future monitoring results.

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the Bruderheim site are presented in Table 13. Data for all sampled layers are presented for both sites for the initial four sampling years. No analyses were completed for East sub-site samples below 10 cm depth for 2003 to 2007, and no layers from the West Sub-site were analyzed in the last two years.

pH

- pH in the West sub-site decreased by up to 0.4 units in the 0-2 cm layer and 0.3 units in the 2-5 cm layer; differences were similar among the four sampling years in the East sub-site.
- These differences were significant for both layers in the West sub-site according to the ANOVA (Table 7 and Appendix C); there was significance only for the 0-2 cm layer in the East sub-site.
- The pH trend at the West sub-site was generally downward, with a slight increase in the last sampling event.
- Other, deeper layers did not show any significant trends over the four initial years for which data were collected.

Base Saturation Percentage

- Base saturation values are relatively high, mainly above 80% in most soil layers.
- Significant differences were indicated by ANOVA (Table 8 and Appendix C) in the upper four layers of the West sub-site, and the upper two layers of the East sub-site.
- The trend in the West sub-site surface three layers was generally downward and then upward in the last three monitoring events for the 0-2 cm layer, and upward in only the last event in the 2-5 and 5-10 cm layers. The values in the initial and last events were 91% and 83%, respectively.
- As with pH, significance was different at the two sub-sites. As indicated previously, the additional sampling events at the East sub-site likely influence the significance.

Ca:Al and BC:Al Ratios

- The West sub-site Ca:Al ratio decreased from 11 to 3 in the 0-2 cm layer, from 8 to 3 in the 2-5 cm layer, and from 4 to 2 in the 5-10 cm layer.
- The differences in the west sub-site values were significant, with the trend being downward, except for an increase in 2003.
- The Ca:Al ratios at the East sub-site, determined only in 1984, 1988 and 1992, showed decreases in the 0-2 and 2-5 cm layers, while the ratios changed only slightly in all other layers.
- The ANOVA (Table 9 and Appendix C) indicated significant differences in log Ca:Al in all layers at both sub-sites. However, the differences in lower layers reflected both decreases and increases over time.

- The BC:Al ratio showed trends similar to the Ca:Al ratio.
- Ca:Al ratios were very low at all sampling depths. BC:Al ratios were somewhat higher than Ca:Al ratios in the surface layers in particular.

Table 13. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Bruderheim Site.

pH ($CaCl_2$) – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	4.8	0.2	3.5	4.7	0.2	4.0	4.5	0.2	3.3	4.5	0.2	3.3	4.7	0.1	3.0	4.9	0.2	3.5	5.1	0.1	2.3
1988	12	4.8	0.2	4.2	4.7	0.1	2.5	4.5	0.1	2.9	4.5	0.1	3.1	4.7	0.1	2.1	4.9	0.2	3.1	5.0	0.1	2.8
1992	12	4.4	0.2	4.1	4.6	0.2	4.0	4.4	0.2	3.4	4.5	0.1	2.5	4.6	0.2	3.4	4.9	0.1	2.9	5.0	0.2	3.6
1996	12	4.5	0.4	8.4	4.6	0.3	6.3	4.6	0.3	6.1	4.6	0.2	5.2	4.8	0.3	5.7	5.0	0.2	4.8	5.2	0.2	4.7

pH ($CaCl_2$) – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	4.6	0.4	9.0	4.7	0.3	5.5	4.7	0.2	3.2	4.7	0.2	4.3	4.9	0.2	4.3	5.2	0.2	2.9	5.3	0.1	2.5
1988	12	4.5	0.4	9.6	4.6	0.3	6.1	4.7	0.2	4.7	4.7	0.2	5.3	5.0	0.2	4.2	5.1	0.2	3.3	5.2	0.2	3.4
1992	12	4.3	0.3	7.5	4.5	0.2	4.2	4.5	0.2	4.4	4.7	0.2	5.3	4.9	0.3	5.5	5.1	0.1	2.6	5.3	0.2	3.8
1996	12	4.2	0.3	6.9	4.4	0.3	6.1	4.5	0.3	6.0	4.6	0.3	6.3	4.9	0.2	3.9	5.1	0.2	3.7	5.2	0.2	3.1
2003	12	4.2	0.3	7.8	4.4	0.3	7.6	4.5	0.3	7.0	.	.	-	.	.	-	.	.	-	.	.	-
2007	12	4.3	0.3	7.4	4.4	0.3	6.8	4.5	0.3	6.0	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	95	2	2	91	3	4	82	6	7	82	7	8	90	3	4	95	2	2	97	1	1
1988	12	96	2	3	92	3	3	83	4	5	83	5	6	90	5	6	95	2	2	97	1	1
1992	12	87	6	7	84	6	7	79	6	8	82	5	7	88	5	6	94	2	2	97	1	1
1996	12	88	9	11	87	9	11	84	8	10	80	12	15	86	7	9	92	4	4	93	4	4

Base Saturation Percentage – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	91	6	7	90	6	6	88	4	4	86	5	6	90	4	5	96	2	2	97	1	1
1988	12	88	12	13	89	8	9	90	6	7	90	6	6	94	3	3	97	2	2	97	1	1
1992	12	78	9	12	84	7	8	83	8	10	87	8	9	93	5	5	95	2	2	97	1	1
1996	12	81	13	16	82	14	17	81	14	17	83	10	12	90	7	8	94	2	3	95	3	4
2003	12	83	9	11	78	14	18	79	17	22	.	.	-	.	.	-	.	.	-	.	.	-
2007	12	83	8	9	83	8	9	85	8	10	.	.	-	.	.	-	.	.	-	.	.	-

Table 13. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Bruderheim Site (concluded)

Ca:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	16	6	35	9	3	32	3	1	28	2	0	18	2	1	45	2	1	42	1	0	41
1988	12	12	5	42	5	1	26	2	1	27	2	0	30	1	0	32	1	0	31	1	0	21
1992	12	8	3	40	5	2	36	3	1	29	2	1	25	2	1	26	2	1	32	1	0	31

Ca:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	11	6	52	8	3	32	4	1	28	3	1	46	2	1	47	3	2	78	2	2	78
1988	12	6	2	40	5	1	30	3	1	33	2	1	33	2	1	29	2	1	39	1	1	46
1992	12	5	1	25	6	1	26	4	1	36	3	1	28	3	1	37	2	1	44	2	1	53
2003	12	8	5	56	9	6	66	8	10	121	.	.	-	.	.	-	.	.	-	.	.	-
2007	12	3	2	46	3	2	68	2	1	76	.	.	-	.	.	-	.	.	-	.	.	-

Base Cation:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	28	11	39	15	4	29	6	1	25	5	1	22	5	2	39	5	2	40	3	1	37
1988	12	21	9	40	8	2	23	4	1	21	3	1	23	3	1	25	3	1	24	2	0	17
1992	12	14	5	38	10	3	31	7	2	25	6	1	17	5	1	20	5	1	22	4	1	21

Base Cation:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	18	9	52	13	4	33	8	2	24	6	2	35	5	2	38	6	5	78	5	3	61
1988	12	11	4	41	8	3	36	6	2	32	4	1	30	3	1	26	3	1	27	3	1	37
1992	12	9	2	22	10	3	27	8	2	31	7	2	22	7	2	31	6	2	33	6	2	41
2003	12	16	8	49	18	11	60	17	18	107	-	-	-	-	-	-	-	-	-	-	-	-
2007	12	7	3	40	6	4	63	3	2	64	-	-	-	-	-	-	-	-	-	-	-	-

4.2.7 Devon Site

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the Devon site are presented in Table 14. Data for all sampled layers are presented for sampling events from 1984 to 1996. No analyses were completed for North sub-site samples below 10 cm depth for 2003 and 2008, and no layers from the South Sub-site were analyzed in the last two years.

pH

- The pH of the 0-2 cm layer at the North sub-site differed by 0.3 units among sampling years; the initial pH was 4.9, and the last pH was 4.6. The pH difference was up to 0.3 units in the 2-5 and 5-10 cm layers.
- The pH difference in the South sub-site was up to 0.3 units among the four sampling events from 1984 to 1992.
- According to the ANOVA (Table 7 and Appendix C), the pH decrease was significant in the 0-2 and 2-5 cm layers of the North sub-site, but not the South sub-site. This result is likely influenced by the additional sampling events for the North sub-site.
- The pH trend in these 0-2 and 2-5 cm layers was downward, with an increase in both layers in 1996.

Base Saturation Percentage

- Base saturation percentages at this site are >90%. Only small differences occurred in this parameter among the sampling years.
- While differences in upper layers as well as some lower layers were indicated as significant by ANOVA (Table 8 and Appendix C), the changes are very small in relation to the high percentages in base saturation at this site. The overall range in values was 91-99%. Nevertheless, the general trend among most layers is toward reduced base saturation over the monitoring period.

Ca:Al and BC:Al Ratios

- The Ca:Al ratios, ranging from about 4-17 in upper soil layers, and from 2-7 in lower soil layers, remained similar or increased slightly over time in all soil layers.
- The BC:Al ratios, ranging from about 6-29 in upper soil layers, and from 4-12 in lower soil layers, show trends similar to the Ca:Al ratio.
- The ANOVA (Table 9 and Appendix C) indicated that differences in the Ca:Al ratio in the 2-5 cm layer of the North sub-site were significant; however, the overall trend was flat.
- The ANOVA also resulted in significance of differences among sampling events in lower soil layers, with most showing an upward trend.

Table 14: Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Devon Site.

pH ($CaCl_2$) – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	4.9	0.3	6.6	4.9	0.3	5.7	4.9	0.2	4.9	4.9	0.3	6.8	5.0	0.4	7.7	5.2	0.4	7.5	5.3	0.4	6.7
1988	12	4.8	0.2	4.4	4.9	0.2	3.1	4.9	0.2	4.3	4.9	0.3	6.4	5.0	0.4	7.9	5.1	0.4	7.6	5.2	0.4	6.7
1992	12	4.8	0.2	4.6	4.7	0.3	5.7	4.7	0.2	5.3	4.7	0.2	4.7	4.8	0.4	8.3	4.9	0.4	7.7	5.0	0.3	6.6
1996	12	4.9	0.3	7.0	5.0	0.3	6.0	5.0	0.3	5.9	5.0	0.3	6.1	4.9	0.2	4.3	5.1	0.3	6.7	5.3	0.2	4.0
2003	12	4.6	0.4	8.1	4.5	0.3	5.7	4.7	0.3	5.9	.	.	-	.	.	-	.	.	-	.	.	-
2008	12	4.6	0.3	6.3	4.7	0.3	7.3	4.8	0.3	6.9	.	.	-	.	.	-	.	.	-	.	.	-

pH ($CaCl_2$) – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	5.0	0.2	3.4	5.0	0.3	5.2	5.0	0.3	5.5	4.9	0.3	6.6	5.0	0.4	7.0	5.2	0.3	6.4	5.2	0.4	7.3
1988	12	4.9	0.3	5.5	5.0	0.3	6.7	5.0	0.4	7.2	5.1	0.3	6.5	5.2	0.38	7.4	5.3	0.4	8.1	5.5	0.4	7.5
1992	12	4.7	0.4	8.3	4.7	0.3	5.7	4.8	0.3	6.0	4.8	0.3	6.1	4.9	0.2	3.5	5.1	0.2	4.5	5.3	0.2	4.2
1992	12	4.8	0.4	9.4	4.9	0.5	9.5	5.0	0.5	9.2	5.1	0.4	8.3	5.1	0.4	8.2	5.2	0.4	7.8	5.3	0.4	7.1

Base Saturation Percentage – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	97	1	1	96	2	2	96	2	2	95	4	5	95	5	6	97	3	3	99	1	1
1988	12	97	1	1	97	1	1	96	2	2	95	3	4	94	6	6	97	3	3	99	1	1
1992	12	95	5	5	94	3	4	92	5	5	92	5	6	93	7	7	95	4	4	98	1	1
1996	12	97	2	2	97	1	1	95	3	3	94	4	4	92	5	6	94	4	4	97	2	2
2003	12	95	2	3	93	4	4	93	3	4	.	.	-	.	.	-	.	.	-	.	.	-
2008	12	95	2	2	93	5	6	93	4	4	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	97	1	1	97	2	2	96	3	3	94	4	4	96	4	4	98	2	2	99	1	1
1988	12	96	2	2	96	3	3	95	4	4	96	3	3	96	3	3	97	2	2	98	1	1
1992	12	93	6	6	94	4	5	94	3	4	94	4	4	95	2	2	97	2	2	98	1	1
1996	12	95	5	5	91	10	11	93	7	8	93	6	7	93	5	5	93	4	4	95	2	2
2003	12	95	2	3	93	4	4	94	3	4	-	-	-	-	-	-	-	-	-	-	-	-

Table 14. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Devon Site (concluded)

Ca:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
1984	12	10	5	50	8	4	52	5	2	43	3	1	26	3	1	26	3	1	50	2	1	31
1988	12	8	3	35	6	3	46	4	2	49	3	1	40	2	1	40	2	1	57	1	1	61
1992	12	12	6	45	8	4	49	5	2	41	4	1	32	7	10	137	4	3	65	4	2	47
2003	12	12	6	53	7	2	32	6	4	76	.	.	-	.	.	-	.	.	-	.	.	-
2008	12	12	4	32	6	3	48	4	7	175	.	.	-	.	.	-	.	.	-	.	.	-

Ca:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	17	7	42	11	5	45	6	3	50	4	1	34	3	1	31	3	1	22	2	1	46
1988	12	13	6	48	8	4	54	5	2	47	4	2	43	3	1	46	2	1	56	2	1	51
1992	12	14	12	84	8	3	38	6	2	34	5	1	30	4	1	21	4	1	27	3	1	40

Base Cation:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	17	9	56	13	7	57	8	4	48	6	2	27	5	1	27	6	3	52	5	1	30
1988	12	13	5	36	10	5	49	6	3	50	5	2	38	4	2	41	4	2	49	4	2	49
1992	12	22	10	46	14	6	47	9	3	38	8	2	29	13	12	98	10	4	42	9	4	41
2003	12	24	12	50	15	5	31	11	8	77	.	.	-	.	.	-	.	.	-	.	.	-
2008	12	20	6	30	10	5	46	7	12	159	.	.	-	.	.	-	.	.	-	.	.	-

Base Cation:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1984	12	29	11	38	17	7	40	10	5	47	6	2	32	6	2	28	5	1	21	5	2	40
1988	12	22	10	47	13	7	55	8	4	47	7	3	45	5	2	41	5	2	44	4	1	35
1992	12	24	18	76	14	5	33	11	3	28	9	2	25	8	1	16	9	2	21	7	2	28

4.2.8 Rocky Mountain House Site

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the Rocky Mountain House site are presented in Table 15. The South sub-site has had seven monitoring events for which data is presented. No analyses were completed for South sub-site samples below 10 cm depth in 2000, 2005 and 2009, and no layers from the North Sub-site were analyzed in the last three years.

pH

- pH in the South sub-site 0-2 cm layer differed by up to 0.7 units among the sampling years, and by up to 0.5 and 0.3 units in the 2-5 and 5-10 cm layers, respectively.
- The ANOVA (Table 7 and Appendix C) indicated a significant difference in the 0-2 cm layer of the South sub-site, but not the North sub-site. The difference in the 2-5 cm layer was significant in both sub-sites.
- The South sub-site trend in pH is downward, with a small increase occurring only in 1993. This layer had an initial pH of 5.3, which decreased to 4.6 in the final year. The North sub-site had a somewhat lower pH of 4.4 initially, and decreased by only 0.2 units up to 2000.
- There were no significant differences in other layers, except for the 30-45 cm layer at the North sub-site, which showed an initial, somewhat sharp rise in pH, followed by a decrease.

Base Saturation Percentage

- The base saturation percentage decreased in the South sub-site from 96% to 90% in the 0-2 cm layer, 95% to 87% in the 2-5 cm layer, and 96% to 92% in the 5-10 cm layer.
- According to ANOVA (Table 8 and Appendix C), these differences are significant. There were some small base saturation increases in some years, but the overall trend was downward.
- In the North sub-site, changes over the five sampling periods did not show significant differences.
- As with pH, the North and South sites appear to be somewhat different in their chemistry, with base saturation being in the 90s in the North site, which has seven years of data, and in the 80s for the South site, which has five years of data.

Ca:Al and BC:Al Ratios

- The South sub-site Ca:Al ratios range from 5 to 22 in the 0-2 cm layer, 3 to 84 in the 2-5 cm layer, and 1 to 152 in the 5-10 cm layer. The high values in these ranges appear to be anomalous, and result in indication of significance according to ANOVA (Table 9 and Appendix C). The trends in both sub-sites are otherwise flat.
- There are no other indications of significant differences in Ca:Al ratios in the South sub-site. The North sub-site shows significance differences in values in two lower layers.
- In both the North and South sub-sites, there is a large range in the Ca:Al ratio. The Al levels in all layers at this site were near analytical detection limits. Small variations in such very low Al levels can lead to marked variability in Ca:Al ratios. Consequently, results for this site must be interpreted with caution.

Table 15: Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Rocky Mountain House Site.

pH ($CaCl_2$) – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	4.4	0.7	14.9	4.5	0.4	9.2	4.6	0.3	6.3	4.7	0.2	4.4	5.1	0.3	6.3	5.5	0.6	11.7	6.7	0.7	10.5
1985	12	4.5	0.3	6.9	4.6	0.3	5.4	4.8	0.3	5.2	4.9	0.3	5.9	5.3	0.3	4.7	5.9	0.5	8.9	7.0	0.4	5.7
1989	12	4.5	0.5	10.0	4.5	0.4	8.8	4.8	0.4	8.0	4.9	0.4	7.1	5.3	0.3	5.9	6.1	0.6	10.3	6.8	0.5	7.4
1993	12	4.6	0.7	15.3	4.8	0.8	16.8	4.9	0.7	13.7	4.9	0.5	10.8	5.3	0.7	13.3	5.8	0.8	13.4	7.2	0.2	2.5
2000	12	4.2	0.3	6.6	4.3	0.3	6.5	4.5	0.2	5.1	.	.	-	.	.	-	.	.	-	.	.	-

pH ($CaCl_2$) – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	5.3	0.3	6.5	5.1	0.3	4.9	5.1	0.3	6.0	5.1	0.2	3.7	5.4	0.3	5.2	6.3	0.7	10.6	7.3	0.2	2.6
1985	12	5.1	0.4	8.2	5.0	0.4	7.6	5.1	0.4	8.5	5.2	0.5	8.9	5.4	0.4	6.8	6.3	0.7	11.7	7.2	0.4	6.1
1989	12	4.9	0.4	7.9	4.9	0.3	5.1	5.0	0.2	4.2	5.2	0.2	3.9	5.4	0.2	4.3	6.3	0.6	8.8	7.0	0.4	5.1
1993	12	5.0	0.3	6.6	5.0	0.4	7.4	5.0	0.3	6.4	5.1	0.3	6.3	5.4	0.3	5.8	6.1	0.7	11.3	7.4	0.1	1.5
2000	12	4.6	0.3	7.4	4.7	0.3	5.3	5.0	0.2	4.8	.	.	-	.	.	-	.	.	-	.	.	-
2005	12	4.7	0.4	9.2	4.8	0.6	13.2	5.0	0.7	14.7	.	.	-	.	.	-	.	.	-	.	.	-
2009	12	4.6	0.4	8.5	4.7	0.4	8.6	4.9	0.3	7.0	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	84	9	11	87	7	8	89	8	9	94	5	6	98	2	2	100	0	0	100	0	0
1985	12	87	7	8	87	6	7	93	3	3	95	4	4	99	1	1	99	0	0	100	0	0
1989	12	88	9	10	84	12	15	91	9	10	95	5	5	99	1	1	100	0	0	100	0	0
1993	12	85	8	10	86	8	9	91	6	6	94	4	5	98	1	1	99	0	1	100	0	0
2000	12	86	5	5	81	8	10	85	7	9	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	96	3	3	95	4	4	96	3	3	98	1	2	99	0	0	100	0	0	100	0	0
1985	12	94	5	6	94	4	4	95	3	4	97	2	2	98	1	1	99	1	1	99	1	1
1989	12	95	4	4	95	3	3	97	2	2	99	1	1	99	1	1	100	0	0	100	0	0
1993	12	95	3	3	95	4	4	96	2	2	98	1	2	99	1	1	100	0	0	100	0	0
2000	12	93	3	4	92	4	5	96	4	4	.	.	-	.	.	-	.	.	-	.	.	-
2005	12	93	5	5	90	8	9	92	7	8	.	.	-	.	.	-	.	.	-	.	.	-
2009	12	90	7	7	87	11	12	92	6	6	.	.	-	.	.	-	.	.	-	.	.	-

Table 15. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Rocky Mountain House Site (concluded)

Ca:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	8	12	146	5	3	71	5	2	46	5	2	35	5	2	39	21	33	154	103	102	99
1985	12	5	2	36	4	2	58	5	3	70	6	5	87	13	14	109	51	49	96	69	47	68
1989	12	5	3	56	4	3	66	4	4	86	3	1	36	6	9	155	65	65	100	54	44	81
2000	12	6	2	34	4	2	48	2	1	74	-	-	-	-	-	-	-	-	-	-	-	-

Ca:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	15	9	61	10	4	45	9	4	46	8	2	28	9	8	91	35	28	79	47	49	105
1985	12	13	11	83	11	13	116	8	5	61	8	7	91	8	9	109	29	24	83	52	34	66
1989	12	6	2	41	5	3	49	5	1	29	4	2	36	4	2	43	43	52	123	37	31	83
2000	12	8	6	72	3	3	83	3	4	132	-	-	-	-	-	-	-	-	-	-	-	-
2005	12	22	35	160	84	254	304	152	268	176	-	-	-	-	-	-	-	-	-	-	-	-
2009	12	7	5	67	6	5	95	7	8	120	-	-	-	-	-	-	-	-	-	-	-	-

Base Cation:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	14	19	135	9	5	60	8	3	40	9	3	34	10	4	38	35	48	137	153	148	96
1985	12	9	3	33	7	4	56	8	5	61	10	8	77	22	22	99	78	68	87	101	69	68
1989	12	9	5	53	7	4	59	7	5	73	6	2	31	10	14	136	96	94	99	79	63	81
2000	12	14	5	34	8	4	46	4	3	67	.	.	-	.	.	-	.	.	-	.	.	-

Base Cation:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1981	12	31	16	51	19	7	37	17	6	35	14	3	24	15	11	76	52	39	74	68	71	104
1985	12	24	18	73	20	20	100	14	7	48	15	11	77	15	13	91	45	34	76	78	55	70
1989	12	11	4	33	11	5	51	10	4	37	9	3	38	8	3	41	63	76	120	54	44	82
2000	12	16	12	71	7	5	72	6	6	111	.	.	-	.	.	-	.	.	-	.	.	-
2005	12	38	58	152	117	345	295	207	357	173	.	.	-	.	.	-	.	.	-	.	.	-
2009	12	15	10	65	11	10	87	14	16	117	.	.	-	.	.	-	.	.	-	.	.	-

4.2.9 Esther Site

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the Esther site are presented in Table 16. Data for all sampled layers are presented for six sampling events from 1982 to 2007. No analyses were completed for North sub-site samples below 10 cm depth in 2002 and 2007, and no layers from the South Sub-site were analyzed in the last two years.

pH

- pH differences among sampling events in surface soil layers of both the North and South sub-sites are very small, with the highest being 0.4 units in the 0-2 cm layer.
- A gradual increase in pH follows by a decrease occurred in the North sub-site, with ANOVA indicating the difference in pH values as significant (Table 7 and Appendix C).
- pH at the South sub-site also was indicated as significant by ANOVA. The overall trend at this sub-site was an increase in pH.

Base Saturation Percentage

- The base saturation percentages are greater than 99% in all soil layers, and no changes occurred among the sampling events.
- Significant differences in the surface layers and some sub-surface layers at both sub-sites were indicated as significant by ANOVA (Table 8 and Appendix C); this is likely a consequence of small true differences appearing as large relative differences within a very narrow range of base saturation. The overall range among all layers at both sub-sites was 99.1-99.9%. There are thus no biologically relevant differences in base saturation percentage at this site.

Ca:Al and BC:Al Ratios

- The Ca:Al and BC:Al ratios in the upper soil layers are higher than at other sites in the central and northern part of the province. Both increases and decreases in these ratios occurred. These were inconsistent between years, with highest values in 1983 and 1991, diminishing to somewhat lower levels in later years.
- Similar to the Rocky Mountain House and Twin Butte sites, the Al levels in all layers at this site were near analytical detection limits. Small variations in such very low Al levels can lead to marked variability in Ca:Al ratios. Consequently, results for this site must be interpreted with caution.

Table 16: Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Esther Site.

pH ($CaCl_2$) – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	5.5	0.2	2.9	5.7	0.2	3.0	5.7	0.2	3.2	5.6	0.2	3.0	5.7	0.2	2.6	5.9	0.1	2.2	6.3	0.3	4.8
1987	12	5.6	0.3	5.9	5.7	0.2	3.7	5.7	0.2	4.2	5.8	0.3	4.5	5.8	0.3	4.3	6.1	0.3	5.4	6.5	0.5	6.9
1991	12	5.6	0.1	2.3	5.6	0.1	2.3	5.5	0.1	2.4	5.5	0.1	1.8	5.7	0.2	2.7	5.9	0.2	2.9	6.3	0.3	5.1
1995	12	5.8	0.2	3.5	5.7	0.2	4.0	5.7	0.3	5.1	5.7	0.3	4.7	5.8	0.3	4.3	6.1	0.3	5.2	6.5	0.4	5.9
2002	12	5.6	0.2	3.4	5.7	0.1	2.1	5.6	0.2	2.8	-	-	-	-	-	-	-	-	-	-	-	-
2007	12	5.5	0.2	3.8	5.7	0.2	3.8	5.7	0.3	4.8	-	-	-	-	-	-	-	-	-	-	-	-

pH ($CaCl_2$) – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	5.3	0.3	5.6	5.7	0.1	2.3	5.6	0.2	2.7	5.6	0.2	2.7	5.7	0.3	4.6	5.9	0.2	3.9	6.2	0.4	6.1
1987	12	5.6	0.1	1.6	5.7	0.1	2.3	5.7	0.2	3.2	5.7	0.2	3.2	5.7	0.2	3.3	6.0	0.2	2.5	6.3	0.3	5.2
1991	12	5.6	0.1	2.3	5.8	0.1	2.4	5.6	0.2	2.7	5.6	0.1	2.5	5.7	0.1	2.3	5.9	0.2	2.9	6.2	0.2	3.2
1995	12	5.7	0.2	4.2	5.7	0.2	4.0	5.6	0.2	3.0	5.6	0.2	2.8	5.8	0.2	2.8	5.9	0.2	3.1	6.1	0.2	3.4

Base Saturation Percentage – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	99	0.2	0.2	99	0.2	0.2	99	0.3	0.3	99	0.3	0.3	100	0.3	0.3	99	0.4	0.4	99	0.5	0.5
1987	12	100	0.2	0.2	100	0.2	0.2	100	0.3	0.3	100	0.3	0.3	100	0.2	0.2	100	0.3	0.3	100	0.3	0.3
1991	12	100	0.3	0.3	100	0.4	0.4	99	0.3	0.3	99	0.3	0.3	100	0.3	0.3	99	0.5	0.5	99	0.5	0.5
1995	12	100	0.2	0.2	100	0.1	0.1	100	0.5	0.5	100	0.1	0.1	100	0.7	0.7	100	0.2	0.2	100	0.1	0.1
2002	12	99	0.6	0.6	99	0.5	0.5	100	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-
2007	12	99	0.9	0.9	100	0.6	0.6	100	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-

Base Saturation Percentage – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	99	0.5	0.5	99	0.2	0.2	100	0.2	0.2	100	0.2	0.2	100	0.3	0.3	100	0.3	0.3	99	0.7	0.7
1987	12	100	0.2	0.2	100	0.1	0.1	100	0.1	0.1	100	0.4	0.4	100	0.3	0.3	100	0.2	0.2	100	0.5	0.5
1991	12	100	0.3	0.3	100	0.1	0.1	99	0.1	0.1	99	0.2	0.2	100	0.2	0.2	100	0.3	0.3	99	0.4	0.4
1995	12	100	0.3	0.3	100	0.3	0.3	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.3	0.3

Table 16. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Esther Site (concluded)

Ca:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	19	13	71	6	2	29	6	3	40	6	2	41	4	2	51	4	2	46	6	4	60
1987	12	5	2	35	6	3	47	5	1	26	5	2	45	5	2	37	8	4	58	9	8	84
1991	12	16	4	28	11	4	35	12	3	25	11	3	24	9	2	23	6	2	25	8	9	116
2002	12	8	5	69	3	1	41	2	1	45	-	-	-	-	-	-	-	-	-	-	-	-
2007	12	10	6	64	5	3	51	4	4	95	-	-	-	-	-	-	-	-	-	-	-	-

Ca:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	24	9	38	6	2	35	4	1	26	4	1	24	5	6	106	4	2	50	5	4	80
1987	12	8	3	40	4	1	34	5	1	26	4	1	18	4	1	22	4	1	28	5	4	68
1991	12	19	5	28	15	5	31	15	5	33	13	4	31	11	3	28	9	3	41	7	3	47

Base Cation:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	48	30	63	15	3	20	14	4	31	11	4	32	8	4	45	9	3	39	13	6	47
1987	12	16	4	26	15	6	38	10	2	23	10	4	40	9	3	32	15	7	49	18	12	67
1991	12	47	12	27	34	9	28	29	7	24	23	5	21	19	4	22	14	3	23	17	15	86
2002	12	21	14	66	8	2	32	5	2	41	-	-	-	-	-	-	-	-	-	-	-	-
2007	12	23	13	58	12	6	46	9	7	78	-	-	-	-	-	-	-	-	-	-	-	-

Base Cation:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1983	12	63	20	33	17	5	31	10	3	27	10	2	21	11	9	81	10	4	42	12	8	64
1987	12	24	7	31	13	4	29	12	4	31	9	1	16	9	2	18	10	3	31	11	6	57
1991	12	53	16	30	45	13	30	42	21	51	29	9	30	24	6	26	20	7	35	18	8	46

4.2.10 Twin Butte Site

Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at the Twin Butte site are presented in Table 17. Data for sampled layers are presented for six sampling events of the West sub-site from 1982 to 2006. No analyses were completed for West sub-site samples below 10 cm depth in 2001 and 2006, and no layers from the South sub-site were analyzed in the last two years.

pH

- pH in the both West and East sub-sites differed among sampling years by 0.2 units or less in most of the layers.
- The pH trend is interpreted as being steady over the monitoring program.

Base Saturation Percentage

- The base saturation percentages are greater than 99% in all soil layers, and no changes occurred among the sampling events. Apparent significant differences indicated by the ANOVA (Table 8 and Appendix C) result from small changes within a very narrow range of values. These are therefore not considered to be tangible differences.

Ca:Al and BC:Al Ratios

- The Ca:Al and BC:Al ratios in the upper soil layers are considerably higher than at other sites, in the upper soil layers. Ca:Al ratios range from about 30 to close to 200, and diminish with depth to levels in the 20s, 30s and 40s. BC:Al ratios in upper layers are much higher than Ca:Al ratios, mainly in the 200s and 300s, and they diminish to 30s and 40s in lower layers.
- Significant differences indicated by the ANOVA (Table 9 and Appendix C) for a number of soil layers are not considered to be valid. As at the Esther and Rocky Mountain House sites, the Al values were very low and near detection limits, giving rise to doubtful values for the Ca:Al and BC:Al ratios. The Al levels in all layers at this site were near analytical detection limits. Small variations in such very low Al levels can lead to marked variability in Ca:Al ratios. Consequently, results for this site must be interpreted with caution.

Table 17: Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Twin Butte Site.

pH ($CaCl_2$) – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	5.8	0.3	4.5	5.5	0.2	3.3	5.4	0.1	2.4	5.5	0.1	2.2	5.6	0.1	1.4	5.7	0.1	2.1	5.9	0.2	2.6
1986	12	5.9	0.4	7.4	5.6	0.4	7.7	5.6	0.5	8.3	5.6	0.5	8.2	5.8	0.5	8.0	5.9	0.4	7.1	6.1	0.5	8.6
1990	12	5.7	0.3	4.4	5.6	0.2	3.2	5.5	0.2	3.1	5.6	0.1	2.1	5.7	0.1	2.1	5.9	0.1	2.4	6.1	0.3	4.4
1994	12	5.9	0.4	6.3	5.6	0.5	8.4	5.6	0.5	9.2	5.6	0.5	8.9	5.8	0.4	7.6	6.1	0.4	6.8	6.4	0.5	7.3
2001	12	5.7	0.2	3.7	5.5	0.3	4.5	5.5	0.3	4.9	-	-	-	-	-	-	-	-	-	-	-	-
2006	12	5.9	0.3	4.4	5.5	0.3	5.6	5.4	0.3	6.3	-	-	-	-	-	-	-	-	-	-	-	-

pH ($CaCl_2$) – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	5.9	0.2	2.7	5.7	0.4	6.3	5.6	0.4	6.7	5.7	0.3	5.8	5.8	0.3	5.2	5.9	0.3	4.9	6.3	0.4	6.7
1986	12	5.9	0.2	3.4	5.7	0.1	1.9	5.6	0.1	2.1	5.6	0.1	2.1	5.7	0.1	2.3	5.9	0.2	2.9	6.3	0.3	4.8
1990	12	6.0	0.1	2.3	5.7	0.2	3.5	5.6	0.2	3.9	5.6	0.2	3.7	5.7	0.2	3.8	5.9	0.2	4.1	6.2	0.3	5.0
1994	12	6.0	0.1	2.0	5.7	0.1	1.9	5.6	0.1	1.6	5.6	0.2	3.6	5.7	0.1	2.3	5.8	0.2	2.6	6.2	0.3	4.2

Base Saturation Percentage – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.0	0.0
1986	12	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1
1990	12	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.0	-	100	0.1	0.1	100	0.0	0.0	100	0.0	0.0
1994	12	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.0	0.0	100	0.1	0.1
2001	12	100	0.2	0.2	100	0.2	0.2	100	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-
2006	12	100	0.1	0.1	100	0.1	0.1	100	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-

Base Saturation Percentage – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	100	0.0	0.0	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1
1986	12	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.7	0.7	100	0.1	0.1	100	0.1	0.1	100	0.2	0.2
1990	12	100	0.0	0.0	100	0.1	0.1	100	0.1	0.1	100	0.0	-	100	0.0	0.0	100	0.1	0.1	100	0.1	0.1
1994	12	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100	0.0	0.0

Table 17. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Twin Butte Site (concluded)

Ca:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	113	45	40	37	13	34	29	16	54	32	12	38	26	26	100	21	9	43	23	6	27
1986	12	135	95	71	156	342	219	89	168	189	53	74	140	34	44	129	62	93	150	176	127	72
1990	12	101	63	63	55	16	29	30	5	17	23	6	24	26	6	21	23	5	24	66	125	190
2001	12	110	39	36	82	46	55	84	50	59	-	-	-	-	-	-	-	-	-	-	-	-
2006	12	92	173	189	90	174	193	96	163	169	-	-	-	-	-	-	-	-	-	-	-	-

Ca:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	170	95	56	119	76	64	69	51	74	38	19	50	31	19	61	21	12	56	44	52	118
1986	12	287	217	75	136	43	32	84	43	51	51	24	47	24	7	30	19	7	36	33	38	112
1990	12	110	32	29	53	18	34	38	17	45	29	13	44	30	20	67	21	12	56	38	46	121

Base Cation:Al Ratio – West Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	336	136	40	97	36	37	66	33	50	67	22	32	47	14	30	36	13	37	38	10	28
1986	12	313	186	59	301	519	172	175	253	145	101	114	113	59	64	109	95	128	135	411	302	74
1990	12	237	129	55	131	41	32	75	13	18	55	10	18	51	10	20	43	9	22	93	148	158
2001	12	289	115	40	204	113	55	189	107	57	-	-	-	-	-	-	-	-	-	-	-	-
2006	12	263	420	160	203	354	174	189	300	159	-	-	-	-	-	-	-	-	-	-	-	-

Base Cation:Al Ratio – East Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1982	12	372	191	51	217	135	62	126	88	70	69	33	48	53	29	55	38	16	43	72	73	101
1986	12	545	366	67	333	304	91	151	72	48	89	41	46	40	11	29	32	11	35	55	53	96
1990	12	271	91	34	112	34	31	72	28	39	52	20	38	50	28	55	36	16	43	61	66	108

4.2.11 Fort Saskatchewan Site

The Fort Saskatchewan site is a recent addition to the Long Term Soil Acidification Monitoring Program. It was established and sampled in 2008. A forest fire in spring, 2009, eliminated most of the vegetation at both sub-sites. The site was re-sampled in 2010 to document soil chemical properties which may have changed as a result of the fire. Mean values for pH, base saturation percentage, Ca:Al ratio and BC:Al ratio at this site are presented in Table 18. Data for all sampled layers are presented for the 2008 sampling event, and data to 5 or 10 cm are presented for the 20-10 samples.

pH

- pH in the 0-2 cm layer of the North sub-site was 5.1 in both years, but increased from 5.3 to 5.6 in the South sub-site.
- pH in the 2-5 cm layer decreased by 0.3 or 0.4 units in both sub-sites, and decreased by 0.6 units in the North sub-site (data for the South sub-site were not obtained); this latter change was indicated as significant by ANOVA (Table 7 and Appendix C).

Base Saturation Percentage

- Base saturation percentages were greater than 90% in all soil layers in the south sub-site; the North sub-site was similar except that 2-5, 5-10 and 10-15 cm layer values were in the 80s.
- The values increased between the first and second sampling events in the top two layers at both sites; however, there was a slight decrease in the 5-10 cm layer of the North sub-site.
- ANOVA (Table 8 and Appendix C) indicated that none of these changes was significant.

Ca:Al and BC:Al Ratios

- The Ca:Al and BC:Al ratios were higher in upper horizons as compared to lower horizons; this distribution is the reverse as compared to most other sites.
- These ratios increased in the 0-2 and 2-5 cm layers from 2008 to 2010m and decreased in the 5-10 cm layer in the North sub-site.
- The increase in ratios may be related to input of base cations to the soil surface from ash produced during the forest fire of 2009.

Table 18: Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Fort Saskatchewan Site.

pH ($CaCl_2$) – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	5.1	0.5	9.7	5.1	0.4	6.9	5.1	0.2	4.9	5.2	0.2	4.3	5.6	0.2	3.7	5.9	0.2	2.7	6.0	0.2	3.7
2010	12	5.1	0.8	14.6	4.7	0.6	12.8	4.5	0.5	10.8	.	.	-	.	.	-	.	.	-	.	.	-

pH ($CaCl_2$) – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	5.3	0.6	11.7	5.4	0.4	7.6	5.4	0.3	5.4	5.4	0.3	5.5	5.9	0.2	3.1	6.0	0.2	2.8	6.2	0.1	2.3
2010	12	5.6	0.8	13.7	5.1	0.6	11.5	.	.	-	.	.	-	.	.	-	.	.	-	.	.	-

Base Saturation Percentage – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	92	7	7	84	10	12	83	9	11	86	6	7	96	2	2	97	2	2	98	2	2
2010	12	94	7	8	86	11	13	81	11	14	-	-	-	-	-	-	-	-	-	-	-	-

Base Saturation Percentage – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	93	7	7	91	8	8	92	5	6	93	4	4	98	1	1	99	1	1	100	0.4	0.4
2010	12	97	3	3	93	6	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 18. Soil pH, Base Saturation, Ca:Al Ratio and Base Cation:Al Ratio at the Fort Saskatchewan Site (concluded).

Ca:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	27	40	146	13	2	17	8	9	106	5	3	74	5	3	63	5	4	81	8	7	88
2010	12	72	102	141	21	54	264	4	8	195	-	-	-	-	-	-	-	-	-	-	-	-

Ca:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	33	56	173	15	24	164	12	21	170	6	5	98	1	0.4	67	0.4	0.2	50	0.3	0.1	33
2010	12	63	107	170	15	25	170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Base Cation:Al Ratio – North Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	49	69	142	22	36	160	16	14	91	10	6	65	12	8	64	11	9	80	18	16	88
2010	12	129	173	133	39	101	258	9	15	177	-	-	-	-	-	-	-	-	-	-	-	-

Base Cation:Al Ratio – South Sub-Site

Depth (cm)		0-2			2-5			5-10			10-15			15-30			30-45			45-60		
Year		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
2008	12	52	82	158	25	36	148	23	37	161	10	9	86	2	1	50	1	1	48	1	0.3	35
2010	12	104	164	159	27	43	163	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

4.3 STATISTICAL ANALYSIS SUMMARY

Decreasing trends in pH and base saturation percentage were observed in some of the sites, particularly in the topmost soil layer (0-2 cm, and less so in the 2-5 cm and 5-10 cm layers). Small decreases of up to 0.5 pH units in these layers were apparent in the Cold Lake, High Prairie, Bruderheim, Devon and Rocky Mountain House sites. Each of these are forested sites, and one other, the Fort McMurray site, showed a different pattern consisting of an increase in pH in initial years of monitoring, followed by a decrease in 2004, and then another increase to pre-2004 values in the 2008 sampling event.

Decreasing base saturation percentage over time was observed in the Fort McMurray, Cold Lake, High Prairie, Devon and Bruderheim sites. Base saturation generally increases or decreases with soil pH, and at the Fort McMurray site, the trend generally corresponds to that of pH. pH values in the grassland sites – Esther and Twin Butte – were somewhat higher than those of forested sites, and although the change at the Esther site was statistically significant, the magnitude of change was 0.1-0.2 units, which is not considered to be biologically significant.

Base cation to aluminum ratio and calcium to aluminum ratio showed statistically significant variations within some sites over time, but consistent trends were not evident at any except the Bruderheim site, where a decrease in ratio is noted. Both grassland sites (Esther, Twin Butte) had much higher ratios for both Ca:Al and BC:Al parameters than the forest sites. Ratios in some forested sites were very low, particularly in the Fort McMurray, Cold Lake, High Prairie, Bruderheim and Fort Saskatchewan sites. In many cases, the ratio showed a decrease followed by an increase, and then decreased again (Cold Lake, Bruderheim, Devon, Rocky Mountain House, and to a lesser extent, the Fort McMurray site. This suggests input of base cations, particularly in the 2000 to 2004 period. While input from forest fires is a possibility, it is not possible to definitely attribute the increase in ratios.

Sub-sites without analytical results for the last two or three years of monitoring tended to display definite trends. In general, the accompanying sub-sites with more years of data showed similar trends. As noted above, some parameters reversed trends in the last one or two years of monitoring. As the monitoring program continues, the interpretive value of the sites with fewer years of data will be limited. Therefore, it is recommended that analyses be carried out on soil samples from each of the sub-sites at each site, to enable more balanced comparison of results at each site and to provide more rigour to the statistical analysis of differences and trends.

ANOVA and linear modelling approaches showed significant differences even in instances where there was a 0.1 or 0.2 pH change, or where other parameters showed very small differences. It is therefore important to distinguish between statistically important and biologically important differences. Statistically significant changes may be evidence of changes related to acid deposition but may not be of a magnitude likely to cause biological effects.

As indicated previously, both multivariate statistical approaches have limitations. Regression (linear modelling) should be applied mainly to support the ANOVA analysis. In future analyses, relationships among the variables should be examined in order to improve inference. This may be difficult because of the non-linear behaviour in the extremes of the relationships.

5.0 SOIL ACIDIFICATION MODELLING OF LTSAM SITES

5.1 SUMMARY OF DATA INPUTS

The starting parameters for soils used in simulations are given in Table 19. The taxonomy and some general descriptive features of the soils are indicated along with input data described previously (Section 3.5.2.1). Calculations of soil chemistry input variables are presented in Appendix E. The total acid input is also provided in Table 19 in terms of H^+ input.

Table 19: ARC Model System Definition Variables.

Site	Fort McMurray	Cold Lake	High Prairie	Bruderheim	Fort Saskatchewan	Devon	Rocky Mountain House	Esther	Twin Butte
Soil Subgroup	E.DYB [z]	E.DYB	E.DYB	E.DYB	E.DYB	E.DYB	BR.GL	O.DB	O.BC
Soil Series	Mildred	Liza	Heart	Nestow	Nestow	Nestow	Prentice	Wainwright	Dunvargan
LFH Thickness (cm)	2	2	2	2	2.5	6	4	-	1
LFH pH_C	3.6	4.4	4.1	4.0	4.8	4.6	4.7	-	5.8
LFH Total Bases ($kmol_c\ ha^{-1}$)	2.3	5.5	4.1	5.8	9.7	38.5	15.7	-	4.6
LFH CEC ($kmol_c\ ha^{-1}$)	11.1	12.4	11.8	16.5	14.6	76.1	29.6	-	5.45
LFH Base Saturation (%)	21	44	35	35	67	51	53	-	85
Mineral Soil Thickness (cm)	25	25	25	25	25	25	25	25	25
Mineral Soil pH_C	4.6	4.8	4.9	4.7	4.9	4.8	5.2	5.8	5.4
Mineral Bases ($kmol_c\ ha^{-1}$)	15.3	32.8	38.8	73.9	116	139	256	166	777
Mineral CEC ($kmol_c\ ha^{-1}$)	68.6	93.0	110	135	181	195	337	222	922
Mineral Base Saturation (%)	22	35	35	55	64	71	76	75	84
Precipitation ($cm\ y^{-1}$)	45	46	50	50	50	50	51	31	54
Litter ET ($cm\ y^{-1}$)	13	14	13	14	14	19	16	-	16
Perc below Litter ($cm\ y^{-1}$)	33	32	37	36	36	31	35	-	38
Perc into Mineral ($cm\ y^{-1}$)	33	32	37	36	36	31	35	31	38
ET from Mineral ($cm\ y^{-1}$)	9	13	14	14	14	16	18	22	30
Perc below 25 cm ($cm\ y^{-1}$)	23	19	23	22	22	15	17	9	8
CO_2 Partial Pressure (atm)	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Weathering ($kmol_c\ ha^{-1}\ y^{-1}$)	0.07	0.07	0.07	0.07	0.07	0.10	0.10	0.07	0.50
Activity Coefficient of Al^{3+}	0.720	0.727	0.750	0.692	0.692	0.663	0.714	0.700	0.548
Activity Coefficient of Al^{2+}	0.803	0.808	0.824	0.782	0.782	0.761	0.799	0.789	0.670
a in pH = a(BSat) + b	2.25	2.25	2.25	2.25	2.25	2.25	2.32	3.18	3.18
b in pH = a(BSat) + b	3.52	3.52	3.52	3.52	3.52	3.52	3.35	3.14	3.14
Acid Input ($kmol_c\ H^+\ ha^{-1}\ y^{-1}$)	0.05, 0.1, 0.2, 0.3, 0.5, 0.7, 1.0								
Years of Iteration	300								
Increment of Years	5								

[z] Abbreviations: E.DYB – Eluviated Dystric Brunisol; O.DB – Orthic Dark Brown; BR.GL – Brunisolic Gray Luvisol; O.BC – Orthic Black Chernozem

CEC – cation exchange capacity; pH_C – pH determined in $CaCl_2$ solution; ET – evapotranspiration; Perc – percolation

$kmol_c\ ha^{-1}$ – kilomoles of ionic charge per hectare; y^{-1} – per year; atm - atmosphere

5.2 MODEL RESULTS

The ARC model predicted values for pH, base saturation, solution Al^{3+} concentrations, and BC:Al ratios on a yearly basis for 300 years. Data for Years 0, 50, 100 and 300 were extracted from tabulated model output data for the 300 year period and presented in Table 20. The model simulations are also presented in graphical format in Appendix C. The model determined change in soil chemistry over time for the LFH soil horizon as well as the top 0-25 cm mineral layer. While many processes such as organic matter decomposition and nutrient release occur in the LFH layer, the critical loads are based only on the mineral layer because most plant roots are located here, and the effects of soil acidification have mainly been examined with respect to vascular species (see Section 3.5.5.2).

Table 20: Changes in Soil Chemistry of LTSAM Plot Soils Under Different Acid Loadings.

Acid Input	pH_H				Base Saturation				BC:Al Ratio			
(kmol ha^{-1} y^{-1})	0 y	50 y	100 y	300 y	0 y	50 y	100 y	300 y	0 y	50 y	100 y	300 y
Fort McMurray - Eluviated Dystric Brunisol												
0.05	5.0	4.6	4.6	4.6	0.22	0.007	0.007	0.007	13	8	8	8
0.1	5.0	4.6	4.6	4.6	0.22	0.007	0.007	0.007	13	8	8	8
0.2	5.0	4.6	4.6	4.6	0.22	0.007	0.007	0.007	13	8	8	8
0.3	5.0	4.6	4.6	4.6	0.22	0.007	0.007	0.007	13	8	8	8
0.5	5.0	4.6	4.6	4.6	0.22	0.007	0.007	0.007	13	8	8	8
0.7	5.0	4.6	4.6	4.6	0.22	0.007	0.007	0.007	13	8	8	8
1.0	5.0	4.6	4.6	4.6	0.22	0.007	0.007	0.007	13	8	8	8
Cold Lake – Eluviated Dystric Brunisol												
0.05	5.2	5.0	4.9	4.8	0.35	0.27	0.22	0.18	16	13	12	11
0.1	5.2	5.0	4.9	4.8	0.35	0.27	0.22	0.18	16	13	12	11
0.2	5.2	5.0	4.9	4.8	0.35	0.27	0.22	0.18	16	13	12	11
0.3	5.2	5.0	4.9	4.8	0.35	0.27	0.22	0.18	16	13	12	11
0.5	5.2	4.9	4.8	4.7	0.35	0.23	0.16	0.13	16	12	11	10
0.7	5.2	4.8	4.6	4.6	0.35	0.16	0.08	0.06	16	10	9	8
1.0	5.2	4.6	4.5	4.5	0.35	0.06	0.001	0.001	16	8	7	7
High Prairie – Eluviated Dystric Brunisol												
0.05	5.3	4.9	4.7	4.6	0.35	0.13	0.04	0.02	18	11	9	8
0.1	5.3	4.9	4.7	4.6	0.35	0.13	0.04	0.02	18	11	9	8
0.2	5.3	4.9	4.7	4.6	0.35	0.13	0.04	0.02	18	11	9	8
0.3	5.3	4.9	4.7	4.6	0.35	0.13	0.04	0.02	18	11	9	8
0.5	5.3	4.9	4.7	4.6	0.35	0.13	0.04	0.02	18	11	9	8
0.7	5.3	4.9	4.7	4.6	0.35	0.13	0.04	0.02	18	11	9	8
1.0	5.3	4.7	4.6	4.6	0.35	0.08	0.002	0.002	18	10	8	8
Bruderheim – Eluviated Dystric Brunisol												
0.05	5.1	4.7	4.5	4.5	0.55	0.34	0.28	0.26	15	9	8	8
0.1	5.1	4.7	4.5	4.5	0.55	0.34	0.28	0.26	15	9	8	8
0.2	5.1	4.7	4.5	4.5	0.55	0.34	0.28	0.26	15	9	8	8
0.3	5.1	4.7	4.5	4.5	0.55	0.34	0.28	0.26	15	9	8	8
0.5	5.1	4.7	4.5	4.5	0.55	0.34	0.28	0.26	15	9	8	8
0.7	5.1	4.7	4.5	4.5	0.55	0.34	0.28	0.26	15	9	8	8
1.0	5.1	4.7	4.5	4.5	0.55	0.34	0.28	0.26	15	9	8	8

Table 20. Changes in Soil Chemistry of LTSAM Plot Soils Under Different Acid Loadings (concluded).

Acid Input	pH_H				Base Saturation				BC:Al Ratio			
(kmol ha^{-1} y^{-1})	0 y	50 y	100 y	300 y	0 y	50 y	100 y	300 y	0 y	50 y	100 y	300 y
Fort Saskatchewan – Eluviated Dystric Brunisol												
0.05	5.6	5.5	5.4	5.2	0.64	0.60	0.56	0.44	26	23	21	16
0.1	5.6	5.5	5.4	5.2	0.64	0.60	0.56	0.44	26	23	21	16
0.2	5.6	5.5	5.4	5.2	0.64	0.60	0.58	0.47	26	24	22	17
0.3	5.6	5.5	5.4	5.0	0.64	0.60	0.54	0.38	26	23	20	13
0.5	5.6	5.4	5.2	4.7	0.64	0.55	0.45	0.26	26	21	16	10
0.7	5.6	5.3	5.0	4.6	0.64	0.50	0.36	0.21	26	18	12	9
1.0	5.6	5.1	4.7	4.5	0.64	0.43	0.24	0.17	26	15	9	8
Devon - Eluviated Dystric Brunisol												
0.05	5.2	5.1	5.0	4.9	0.71	0.67	0.64	0.56	16	15	14	12
0.1	5.2	5.1	5.0	4.9	0.71	0.67	0.64	0.56	16	15	14	12
0.2	5.2	5.1	5.0	4.9	0.71	0.67	0.64	0.56	16	15	14	12
0.3	5.2	5.1	5.0	4.9	0.71	0.67	0.64	0.56	16	15	14	12
0.5	5.2	5.1	4.9	4.7	0.71	0.65	0.59	0.48	16	14	12	9
0.7	5.2	5.0	4.8	4.6	0.71	0.62	0.52	0.40	16	13	11	8
1.0	5.2	4.9	4.6	4.4	0.71	0.57	0.43	0.32	16	12	8	7
Rocky Mountain House – Brunisolic Gray Luvisol												
0.05	5.6	5.5	5.5	5.3	0.76	0.73	0.70	0.62	26	24	23	18
0.1	5.6	5.5	5.5	5.3	0.76	0.73	0.70	0.62	26	24	23	18
0.2	5.6	5.5	5.5	5.3	0.76	0.73	0.70	0.62	26	24	23	18
0.3	5.6	5.5	5.5	5.3	0.76	0.73	0.70	0.62	26	24	23	18
0.5	5.6	5.5	5.4	5.0	0.76	0.71	0.66	0.51	26	23	20	14
0.7	5.6	5.4	5.3	4.8	0.76	0.69	0.61	0.41	26	22	18	10
1.0	5.6	5.3	5.1	4.5	0.76	0.65	0.54	0.29	26	19	15	8
Esther - Orthic Dark Brown												
0.05	6.2	6.2	6.2	6.1	0.75	0.74	0.74	0.73	52	50	49	47
0.1	6.2	6.1	6.1	6.0	0.75	0.73	0.72	0.69	52	49	46	41
0.2	6.2	6.1	6.0	5.7	0.75	0.71	0.68	0.61	52	45	40	30
0.3	6.2	6.0	5.9	5.4	0.75	0.69	0.64	0.52	52	42	35	21
0.5	6.2	5.9	5.6	4.8	0.75	0.65	0.57	0.35	52	36	26	11
0.7	6.2	5.7	5.3	4.5	0.75	0.61	0.49	0.24	52	30	19	7
1.0	6.2	5.5	4.9	4.2	0.75	0.55	0.37	0.17	52	24	12	5
Twin Butte – Orthic Black												
0.05	5.8	5.8	5.8	5.8	0.84	0.84	0.84	0.84	33	32	32	32
0.1	5.8	5.8	5.8	5.8	0.84	0.84	0.84	0.84	33	32	32	32
0.2	5.8	5.8	5.8	5.8	0.84	0.84	0.84	0.83	33	32	32	31
0.3	5.8	5.8	5.8	5.7	0.84	0.84	0.83	0.82	33	32	32	30
0.5	5.8	5.8	5.7	5.6	0.84	0.83	0.82	0.79	33	31	30	27
0.7	5.8	5.7	5.7	5.5	0.84	0.82	0.81	0.75	33	30	28	23
1.0	5.8	5.7	5.6	5.2	0.84	0.81	0.78	0.68	33	29	25	17

5.3 CRITICAL LOAD CRITERIA

Critical load criteria are established on the basis of critical chemical criteria and values. Critical values of model outputs for pH, base saturation percentage (BSat) and BC:Al ratio are discussed in Section 3.5.5.2. Critical chemical values specific to the long term monitoring sites are presented in Table 21. For pH, the threshold value selected for forest soils is pH_H 4.2 (pH in water) (Ulrich et al., 1984). For Chernozemic soils, the value is pH_H 5.6 (section 3.5.5.2). Another pH threshold introduced in Table 21 is the pH_H 25%. This is the initial pH (pH_{Hi}) minus the drop in pH_H due to 25% additional acidity based on the difference between the initial acidity (pH_{Hi}) and the minimum recommended pH (pH_{Hmin}). Critical chemical values for BSat and BC:Al ratio are the minimum recommended values and values equivalent to 75% of the initial values (as discussed in Section 3.5.5.3).

5.4 CRITICAL LOAD DERIVATION

The derivation of critical loads requires consideration of the time frame within which changes in soil chemistry occur. Decisions are required as to whether critical chemical values of soil chemical parameters may be reached in only a few years, or over a longer period. Fifty and one hundred year time periods were selected for these decisions (Section 3.5.5.3). Fifty years is a relatively short period, and its selection is based on the premise that it is of sufficient length to enable detection of an actual acidification trend and to initiate measures to counteract the trend. One hundred years is a longer time frame that results in a lower critical load, and it therefore provides a greater measure of protection. Critical loads corresponding to the CCVs in Table 21 are presented in Table 22.

Table 21: Critical Chemical Values of LTSAM Plot Soils for Base Saturation and BC:Al Ratio.

Site	Critical Chemical Value [z]									
	Soil Series	pH_{Hi}	pH_H 25%	pH_{Hmin}	$BSat_i$	$BSat_i$ 75%	$BSat_{min}$	$BC:Al_i$	$BC:Al_i$ 75%	$BC:Al_{min}$
Brunisols/Luvisols										
Fort McMurray	Mildred	5.0	4.6	4.2	0.22	0.17	0.1	13	10	2
Cold Lake	Liza	5.2	4.7	4.2	0.35	0.26	0.1	16	12	2
High Prairie	Heart	5.3	4.7	4.2	0.35	0.26	0.1	18	14	2
Bruderheim	Nestow	5.1	4.7	4.2	0.55	0.41	0.1	15	11	2
Fort Saskatchewan	Nestow	5.6	4.8	4.2	0.71	0.53	0.1	16	12	2
Devon	Nestow	5.2	4.7	4.2	0.75	0.56	0.1	52	39	2
Rocky Mtn. House	Prentice	5.6	4.8	4.2	0.98	0.74	0.1	26	20	2
Chernozems										
Esther	Wainwright	6.2	6.0	5.6	0.76	0.57	0.1	26	20	2
Twin Butte	Dunvargan	5.8	5.7	5.6	0.84	0.63	0.1	33	25	2

[z] Symbols: BSat - base saturation; BC:Al - base cation to Al ratio; pH_H - pH in water; i - the initial, or model input, value; min - minimum; 75% - percentage of the initial value; pH_H 25% - 25% additional acidity between pH_{Hi} and pH_{Hmin}.

Table 22: Critical Loads (kmol ha^{-1} y^{-1}) of LTSAM Soils Derived from pH_H, Base Saturation and BC:Al Ratio.

Site	Soil Series	Time (years)	Critical Chemical Value [z]					
			pH_H 25%	pH_{Hmin}	$BSat_i$ 75%	$Bsat_{min}$ =0.1	$BC:Al_i$ 75%	BC:Al=2
Fort McMurray	Mildred	50	<0.1	>1	<0.1	<0.1	<0.1	>1
		100	<0.1	>1	<0.1	<0.1	<0.1	>1
Cold Lake	Liza	50	0.8	>1	0.4	0.8	0.5	>1
		100	0.6	>1	<0.1	0.6	0.3	>1
High Prairie	Heart	50	1	>1	<0.1	>0.9	<0.1	>1
		100	<0.1	>1	<0.1	<0.1	<0.1	>1
Bruderheim	Nestow	50	<0.1	>1	0.1	>1	<0.1	>1
		100	<0.1	>1	<0.1	>1	<0.1	>1
Fort Saskatchewan	Nestow	50	>1	>1	0.8	>1	0.7	>1
		100	0.9	>1	0.4	>1	0.3	>1
Devon	Nestow	50	>1	>1	>1	>1	1	>1
		100	0.5	>1	0.7	>1	0.5	>1
Rocky Mountain House	Prentice	50	>1	>1	>1	>1	0.9	>1
		100	0.7	>1	0.9	>1	0.5	>1
Esther	Wainwright	50	0.3	>1	0.9	>1	0.4	>1
		100	0.2	1	0.5	>1	0.2	>1
Twin Butte	Dunvargan	50	0.7	>1	>1	>1	>1	>1
		100	0.5	>1	>1	>1	>1	1

[z] Symbols: BSat - base saturation; BC:Al - base cation to Al ratio; pH_H - pH in water; i - the initial, or model input value; 75% - percentage of the initial value; pH_H25% - 25% additional acidity between pH_H and pH_{Hmin}.

5.5 COMPARISON OF CRITICAL LOADS AND MONITORING DATA

The following discusses the critical loads at each monitoring site, along with comparison with the monitoring data.

Fort McMurray Site

The Mildred soil at the Fort McMurray site has a very low critical load for pH_H 25%, both BSat critical values, and for BC:Al 75%. Monitoring results for the Fort McMurray site did not show definite trends for pH_H or BC:Al ratio. The modelling results suggest that reductions could occur with acid deposition at levels <0.1 kmol ha^{-1} y^{-1}. The regional estimate for the acid deposition level (the potential acid input, or PAI) in the Fort McMurray area is 0.12 kmol ha^{-1} y^{-1} (Table 2). The critical load for this monitoring site may therefore be exceeded under current acid deposition levels.

Cold Lake Site

Using the lowest critical load derived for pH_H, BSat and BC:Al ratio in the Liza soil at the Cold Lake site, the 50 year critical load is 0.4 kmol H^+ ha^{-1} y^{-1}, and the 100 year critical load is <0.1

kmol ha^{-1} y^{-1}. The monitoring results show a decreasing trend for pH_H and BSat in the 0-2 and 2-5 cm layers. Based on modelling results, this site is less sensitive than the Fort McMurray site. The regional acid deposition estimate for the Cold Lake area is 0.11 kmol H^+ ha^{-1} y^{-1}. The potential acid input is thus somewhat less than the 50 year critical load of 0.4 kmol H^+ ha^{-1} y^{-1}. However, the regional estimated PAI does not preclude the possibility of higher PAI in some parts of the region, and the PAI may in fact be higher than 0.11 kmol H^+ ha^{-1} y^{-1} in places.

High Prairie Site

The lowest critical load for the Heart soil at the High Prairie site is <0.1 kmol H^+ ha^{-1} y^{-1} for both the 50 and 100 year periods. This site showed trends for decreasing pH_H, BSat and BC:Al ratio in monitoring from 1983 to 2002. The regional acid deposition estimate for the High Prairie area is 0.05 kmol H^+ ha^{-1} y^{-1}. The potential acid input is thus near the 50 year critical load.

Bruderheim Site

The lowest critical load for the Nestow soil at the Bruderheim site is <0.1 kmol H^+ ha^{-1} y^{-1} for both the 50 and 100 year periods. This site showed trends of decreasing pH_H and BSat in the topmost layers in monitoring from 1984 to 2003. The regional acid deposition estimate for the High Prairie area is 0.11 kmol H^+ ha^{-1} y^{-1}. The potential acid input is thus near the 50 year critical load for this site.

Fort Saskatchewan Site

The lowest critical load for the Nestow soil at the Fort Saskatchewan site is 0.7 kmol H^+ ha^{-1} y^{-1} for the 50 year period and 0.3 kmol H^+ ha^{-1} y^{-1} for the 100 year period. This is a new site and, although differences in parameters were noted between the two sampling events, these were only two years apart and are not considered to demonstrate a trend. The regional acid deposition estimate is the same as that for the Bruderheim site (0.11 kmol H^+ ha^{-1} y^{-1}). The potential acid input is thus greater than 50 year critical load for this site.

Devon Site

The lowest critical load for the Nestow soil at the Devon site is 1 kmol H^+ ha^{-1} y^{-1} for the 50 year period and 0.5 kmol H^+ ha^{-1} y^{-1} for the 100 year period. The Devon soil provides somewhat more pH buffering as compared to the preceding four sites. This site showed a decreasing pH_H trend in the topmost layers. The regional acid deposition estimate for the Devon area is 0.17 kmol H^+ ha^{-1} y^{-1}. The potential acid input is thus somewhat lower than the 50 or 100 year critical load for this site. Although the regional estimated PAI does not preclude the possibility of higher PAI in some parts of the region, the difference between the critical and actual loads is relatively substantial.

Rocky Mountain House Site

The lowest critical load for the Prentice soil at the Rocky Mountain House site is 0.9 kmol H^+ ha^{-1} y^{-1} for the 50 year period and 0.5 kmol H^+ ha^{-1} y^{-1} for the 100 year period. Similar to the Devon soil, the soil at this site provides somewhat more pH buffering as compared to the northern four sites. This site showed a decreasing pH_H trend in the topmost layers of in monitoring from 1984 to 2003; small decreases in BSat and BC:Al ratio were inconsistent between the two plots at the site. The regional acid deposition estimate for the Rocky Mountain House area is 0.09 kmol H^+ ha^{-1} y^{-1}. The potential acid input is thus somewhat lower than the 50 or 100 year critical load for

this site. Although the regional estimated PAI does not preclude the possibility of higher PAI in some parts of the region, the difference between the critical and actual loads is relatively substantial.

Esther Site

The lowest critical load for the Wainwright soil at the Esther site is 0.3 kmol H^+ ha^{-1} y^{-1} for the 50 year period and 0.2 kmol H^+ ha^{-1} y^{-1} for the 100 year period. Monitoring did not show any consistent changes in chemical criteria between 1982 and 2001. The regional acid deposition estimate for the Esther area is 0.06 kmol H^+ ha^{-1} y^{-1}. The potential acid input is thus somewhat lower than the 50 or 100 year critical load for this site. The regional estimated PAI does not preclude the possibility of higher PAI in some parts of the region, and the regional deposition is more similar to the critical load than in the Devon and Rocky Mountain House sites.

Twin Butte Site

The lowest critical load for the Dunvargan soil at the Twin Butte site is 0.7 kmol H^+ ha^{-1} y^{-1} for the 50 year period and 0.5 kmol H^+ ha^{-1} y^{-1} for the 100 year period. This site has considerable buffering capacity as compared to the other seven sites. Monitoring did not show any consistent changes in chemical criteria between 1982 and 2001. The regional acid deposition estimate for the Twin Butte area is 0.00 kmol H^+ ha^{-1} y^{-1}; i.e., the acid deposition at this site can be considered as being equivalent to background levels. The regional estimated PAI does not preclude the possibility of higher PAI in some parts of the region. The difference between the critical and actual loads is relatively substantial.

Discussion

Soils at six of the long term monitoring sites are forest soils, five of which are Brunisols and one a Luvisol. All of these soils are very sandy and have relatively low acid buffering capacity. All of the soils showed some trend toward decreasing pH, BSat and/or BC:Al ratio, although the Devon and Rocky Mountain House soils appear to have more buffering than the other soils. The regional PAI appears to be more or less equivalent to the critical load at the Fort McMurray site, and the critical load and regional PAI are fairly similar at the Cold Lake, High Prairie and Bruderheim sites. As such, these sites have potential to demonstrate further change in the future if current estimated levels of PAI continue or increase. The Devon and Rocky Mountain House sites are likely to show slower change over time. Similarly, the Chernozemic soil at the Esther site shows low buffering capacity. Although the PAI at this site is low, the critical load is also relatively low, and the site could show change in the future. The Twin Butte site is considerably more buffered than all other sites, and this is substantiated by no detectable changes in soil chemistry and by relatively high critical loads. As such, continued monitoring at this site should be re-evaluated.

Some aspects of the ARC soil acidification model must be considered when comparing model results with modelling results. The ARC model predicts acidification parameters for the bulk 25 cm topsoil layer. The monitoring results show changes more consistently in the surface 0-2 and 2-5 cm layers than in lower layers. Results of modelling with monitoring data are thus not comparable, except to indicate that some acidification has possibly been initiated, and that these indications of acidification occur in the most sensitive of the monitoring site soils, which is in accordance with model predictions.

Trends in Soil Acidification in Alberta

Another aspect of the ARC model is that extreme cases of low buffering are not handled well. The simulation of the Fort McMurray site, for example, resulted in extremely rapid drop in base cation content, with pH levelling off at pH_H 4.6. In theory, the pH can diminish to somewhat lower levels. This pH is thus an artefact of the model.

The model also predicted very low critical loads for sites such as Fort McMurray, Cold Lake and High Prairie. This occurs for reasons related to the above. In soils where the exchangeable cation pool is very low, the model predicts rapid depletion to threshold values, and the critical load is shown to be <0.1 kmol H^+ ha^{-1} y^{-1} in some sites. Previous versions of the ARC model resulted in a critical load derivation of about 0.2 kmol H^+ ha^{-1} y^{-1} for the Mildred soil (Turchenek et al., 1992). The model results basically demonstrate that the critical load is very low. Also, the modelling indicates that pH differences, particularly in the Fort McMurray soil, will be difficult to detect because of the narrow range of pH decrease. However, BSat measures show a wider range and should be more readily detectable if they in fact diminish as a consequence of external acidic additions. The Fort McMurray site may be showing this characteristic, because base saturation decrease was significant in the topmost sampled layers, while pH did not show a definite trend. It is thus important that base saturation percentage continue to be monitored as this could show a clear acidification trend sooner than pH. Similarly, the BC:Al (or Ca:Al) ratio also shows a relatively wide range as compared to pH, and continued measurement of this parameter is warranted.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Acidification Trends

Decreasing trends in pH and base saturation percentage were observed in some of the sites, particularly in the topmost soil layers (0-2 cm, 2-5 cm, and less so in 5-10 cm layers). Small decreases of up to 0.5 pH units in these layers were apparent in the Cold Lake, High Prairie, Bruderheim, Devon and Rocky Mountain House sites. The Fort McMurray site showed increasing pH in the initial few monitoring events, and then showed a decrease followed by another increase in 2004 and 2008, respectively.

Decreasing base saturation percentage was also apparent in the Fort McMurray, Cold Lake, High Prairie, Devon and Bruderheim sites.

Base cation to aluminum ratio and calcium to aluminum ratio showed statistically significant variations within some sites over time, but with the exception of a downward trend at the Bruderheim site, there were no evident overall patterns common to the other sites over time. Both grassland sites (Esther, Twin Butte) had much higher ratios for both Ca:Al and base cation:Al parameters as compared to the forest sites.

Paired Sub-Sites

Sub-sites in which analytical results were not available for the last two or three years of monitoring tended to display definite trends, and these in general corresponded to trends of the accompanying sub-site with more years of data. As noted above, some parameters reversed trends in the last one or two years of monitoring. As the monitoring program continues, the interpretive value of the sites with fewer years of data will be limited. Based on this observation, it is recommended that analyses be carried out on soil samples from each of the sub-sites at each site, to enable more balanced comparison of results at each site and to provide more rigour to the statistical analysis of differences and trends.

Forest Soil Monitoring

Seven of the nine long term sampling sites are located in forest ecosystems in northern and central Alberta. Most of these showed trends of slight downward change in acidification parameters over time. Continued monitoring is therefore recommended for all of these sites.

Grassland Soil Monitoring

The Esther site is located on sandy, weakly buffered soils. Although definite trends were not detected in this soil, it is the only site representing weakly buffered grassland soils, and continued monitoring is recommended.

The Twin Butte site is situated in relatively well buffered soils, and no trends were detected in the acidification chemistry of these soils. In terms of soil properties only, this site is not likely to show changes until several decades have passed, and the value of continued monitoring is debatable. This is especially relevant in that the area is considered to have little to nil acid deposition. However, many factors enter into siting of monitoring plots. This is the only site in southern Alberta, and it represents the rangeland common in the region. It is recommended that continuation of monitoring at this site be re-considered. An approach that could be considered

involves sampling over longer intervals, such as every eight or ten years, rather than the current four year cycle.

Acidification Modelling and Critical Loads

Application of the ARC acidification model to the monitoring site soils resulted in calculation of very low (<0.1 kmol H^+ ha^{-1} y^{-1}) critical 50 year critical loads for the most poorly buffered soils, namely the Fort McMurray, High Prairie and Bruderheim sites. Very low (<0.1 kmol H^+ ha^{-1} y^{-1}) 100 year critical loads were obtained for the above sites, as well as the Cold Lake site. A 0.2 (<0.1 kmol H^+ ha^{-1} y^{-1}) critical load was derived for the Esther site. The Devon and Rocky Mountain House sites had 50 year critical loads of 1 and 0.9, respectively, and the Twin Butte and Fort Saskatchewan sites each had a critical load of 0.7 kmol H^+ ha^{-1} y^{-1}. These sites had 100 year critical loads of 0.5 kmol H^+ ha^{-1} y^{-1}, except for Fort Saskatchewan which was lower at 0.3 kmol H^+ ha^{-1} y^{-1}. In all of these cases, the model trends over time show very rapid drops in pH, base saturation percentage and base cation:aluminum ratio.

Very low critical loads (such as <0.1 kmol H^+ ha^{-1} y^{-1}) may be partly a model artefact because chemical relationships within the model break down at extremely low base cation levels in the soil. Nevertheless, they demonstrate high sensitivity of some soils, from which the importance of continued monitoring of these soils can be inferred.

Analysis of Archive Samples

The modelling component of this investigation required the re-analysis of historical samples from the initial monitoring events in the early 1980s. Analyses that were carried out included pH, cation exchange capacity, exchangeable cations, and water soluble ions. There was remarkable agreement between the analyses carried out in 2006 and the results from the 1980s. Continued archiving of samples is thus warranted, should other repeat analyses or new analyses be required in the future.

Statistical Analyses

ANOVA and linear modelling approaches showed significant differences even in instances where there was a 0.1 or 0.2 pH change, or where other parameters showed very small differences. It is therefore important to distinguish between statistically important and biologically important differences.

As indicated previously, both multivariate statistical approaches have limitations. Regression (linear modelling) should be applied mainly as supporting the ANOVA analysis because trends in soil chemical changes are not necessarily linear, as assumed by the linear modelling approach.

The analysis of variance appeared to show more definite trends for plots with several years of data as opposed to plots with only three or four years of data. Consideration should be given to analysis of the soil samples from future as well archived samples from previous sampling events. This would enable more balanced comparison of results at each site as well as provide more rigour to the statistical analysis of differences and trends.

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APPENDIX A

DESCRIPTION OF SITES AND SOILS AT THE LONG-TERM MONITORING SITES

Long-Term Soil Acidification Monitoring Site

Site:	Bruderheim
Location:	N.W. 20 – 56 – 20 – W4
Site Description:	sandy eolian blanket; ridged; very gentle slope; very rapidly drained; pine woodland
Soil Subgroup:	Eluviated Dystric Brunisol

Generalized Profile:

LFH	2-0 cm
Ahe	0-5 cm; very dark grayish brown (10YR 3/2 m); fine fire darkened wood particles; loamy sand to sand; very weak fine granular to single grain; loose; clear wavy boundary; very strongly acid
Ae (AB)	5-8 cm; dark brown to brown (10YR 4/3 m); sand; single grain; loose; clear wavy boundary; very strongly acid
Bm_1	8-20 cm; dark yellowish brown (10YR 4/4 m); sand; single grain; loose; clear wavy boundary; very strongly acid
Bm_2	20-40 cm; dark yellowish brown to yellowish brown (10YR 4.5/4 m); sand; single grain; loose; gradual wavy boundary; very strongly acid
Bm_3	40-60 cm; yellowish brown (10YR 5/4 m); sand; single grain; loose; gradual wavy boundary; strongly acid
BC	60-80 cm; yellowish brown (10YR 5/4 to 5.5/4 m); sand; single grain; loose; gradual wavy boundary; strongly acid
C	80-100+ cm; light olive yellow (2.5Y 5/4 m); sand; single grain; loose; strongly acid

Long-Term Soil Acidification Monitoring Site

Site: Devon

Location: S.W. 15 – 51 – 26 – W4

Site Description: sandy eolian blanket; ridged; very gentle to strong slopes; very rapidly to rapidly drained; pine woodland

Soil Subgroup: Eluviated Dystric Brunisol

Generalized Profile:

LFH	6-0 cm
Ahe	0-2 cm; very dark gray (10YR 3/1 m) to very dark grayish brown (10 YR 3/2 m); loamy sand; weak fine platy and weak fine granular; very friable clear wavy boundary; very strongly acid
Ae	2-10 cm; brown (10YR 5/3 m); loamy sand; weak fine platy; very friable; clear wavy boundary; very strongly acid
Btj	10-19 cm; dark yellowish brown (10YR 4/4 m); loamy sand; dark yellowish brown (10 YR 4/4 m); loamy sand; weak fine subangular blocky; very friable to friable; clear wavy boundary; very strongly acid
Bm_1	19-35 cm; dark yellowish brown (10YR 4/4 m); loamy sand to sand; single grain; very friable; gradual wavy boundary; very strongly acid
Bm_2	35-60 cm; dark yellowish brown to yellowish brown (10YR 4.5/4 m); sand; single grain; loose; gradual wavy boundary; strongly acid
BC	60-80 cm; yellowish brown (10YR 4.5/4 m) to light olive brown (2.5YR 5/4 m); sand; single grain; loose; gradual wavy boundary; strongly acid
C	80-110+ cm; olive brown (2.5YR 4/4 m); sand; single grain; loose; medium acid

Long-Term Soil Acidification Monitoring Site

Site:	Esther
Location:	S.E. 33 – 31 – 2 – W4
Site Description:	Sandy glaciofluvial blanket; undulating and ridged landscape; site nearly level; very rapidly drained; natural grazing
Soil Subgroup:	Orthic Dark Brown

Generalized Profile:

Ah	0-16 cm; dark grayish brown to dark brown (10YR 4/2 to 3/3 m); sand; weak fine granular to amorphous and single grain; very friable to loose; clear smooth boundary; medium acid
Bm_1	16-34 cm; brown to dark yellowish brown (10YR 4/3 to 4/4 m); sand; very weak fine prismatic to single grain; very friable to loose; gradual wavy boundary; medium acid
Bm_2	34-55 cm; dark yellowish brown (10YR 4/4 m); sand; single grain; loose; gradual wavy boundary; medium acid
BC	55-100 cm; yellowish brown (10YR 5/4 m); sand; single grain; loose; clear wavy boundary; slightly acid to neutral
C	100-120+ cm; yellowish brown (10YR 5/4 m); sand; single grain; loose; mildly alkaline

Long-Term Soil Acidification Monitoring Site

Site:	Cold Lake
Location:	N.W. 20, S.W. 29 – 64 – 2 – W4
Site Description:	Sandy glaciofluvial blanket thinning in places to a veneer overlying loamy morainal materials at about 0.6 m; inclined; very gentle slopes; very rapidly drained; pine woodland
Soil Subgroup:	Eluviated Dystric Brunisol

Generalized Profile:

LFH	2-0 cm
Ae	0-12 cm; light gray (10YR 7/2 m); sand; single grain; loose; abrupt smooth boundary; extremely acid
AB	12-16 cm; light yellowish brown (10YR 6/4 m) to yellowish brown (10 YR 5/4 m); sand; single grain; loose; gradual wavy boundary; extremely acid
Bm	16-38 cm; yellowish brown (10YR 5/6 m); sand; single grain; loose; gradual wavy boundary; very strongly to strongly acid
BC	38-65 cm; yellowish brown (10YR 5.5/6 m); sand; single grain; loose; diffuse wavy boundary; strongly acid
C	65-100 cm; light yellowish brown (10YR 6/4 m); sand; single grain; loose; strongly acid

Long-Term Soil Acidification Monitoring Site

Site:	Fort McMurray
Location:	S.E. 6, S.W. 5 – 94 – 9 – W4; N.E. 31, N.W. 32 – 93 – 9 – W4
Site Description:	Sandy glaciofluvial blanket; nearly level; very rapidly drained; slightly stony; pine woodland
Soil Subgroup:	Eluviated Dystric Brunisol

Generalized Profile:

LFH	2-0 cm
Ae	0-4 cm; pale brown (10YR 6/3 m); sand; single grain; loose; clear smooth boundary; extremely acid
AB	4-10 cm; yellowish brown (10YR 5/4 m); sand; single grain; loose; sand; clear wavy boundary; extremely acid
Bm_1	10-26 cm; yellowish brown (10YR 5/6 to 5/7 m); sand; single grain; loose; clear smooth boundary; very strongly acid
Bm_2 (Bfj)	26-46 cm; yellowish brown (10YR 5/8 m); sand; single grain; loose; clear smooth boundary; very strongly acid
Bm □	46 –65 cm; brownish yellow (10YR 6/6 m); sand; single grain; loose; clear smooth boundary; strongly acid
BC	65-87 cm; light yellowish brown (10YR 6/4 m); sand; single grain; loose; strongly acid
C	87 to 110+ cm; pale brown (10YR 6/3 m); sand; single grain; strongly acid

Long-Term Soil Acidification Monitoring Site

Site:	High Prairie
Location:	N.E. 33, N.W. 34 – 75 – 17 – W5
Site Description:	Sandy eolian veneer overlying a sandy glaciofluvial blanket; undulating; very gentle slopes; very rapidly drained; pine woodland
Soil Subgroup:	Eluviated Dystric Brunisol

Generalized Profile:

LFH	2-0 cm
Ae	0-2 cm; dark grayish brown (10YR 4/2 d) to gray (10YR 5/1 d); sand; weak fine platy; loose; clear wavy boundary; very strongly acid
Bfj	2-7 cm; dark brown (10YR 3/1 d); fine fire darkened woody particles; sand; single grain; loose; clear wavy boundary; strongly acid
Bm_1	7-18 cm; dark yellowish brown (10YR 4/4 m); sand; single grain; loose; clear wavy boundary; strongly acid
Bm_2	18-37 cm; yellowish brown (10YR 5/4 to 5/6 m); sand; single grain; loose; clear wavy boundary; strongly acid
Bm_3	37 –60 cm; yellowish brown (10YR 5/8 m); sand; single grain; loose; clear wavy boundary; very strongly acid
BC	60-90 cm; yellowish brown (10YR 5/6 m); sand; single grain; loose; gradual wavy boundary; strongly acid
C	90-110+ cm; yellowish brown (10YR 5/4 m); sand; single grain; loose; strongly acid

Long-Term Soil Acidification Monitoring Site

Site: Rocky Mountain House

Location: N.W. 11 – 38 – 8 – W5

Site Description: Ridged sandy eolian blanket; ridged; very gentle to strong slopes; rapidly drained; pine woodland

Soil Subgroup: Brunisolic Gray Luvisol (tending to Podzolic Gray Luvisol)

Generalized Profile:

LFH	4-0 cm
Ae	0-4 cm; gray (10YR 6/1 m) to grayish brown (10 YR 5/2 m); loamy sand to sandy loam; weak fine platy; loose to very friable; clear smooth boundary; strongly acid
Bm (fj)	4-15 cm; yellowish brown (10YR 5/4 m) to dark yellowish brown (10YR 4/4 m); loamy sand; weak fine platy; very friable; clear wavy boundary; strongly acid
Bm or Ae	15-27 cm; yellowish brown (10YR 5/4 m) to pale brown (10YR 6/3 m); loamy sand to sandy loam; weak fine platy; very friable; clear smooth boundary; strongly acid
Bt	27-50 cm; dark yellowish brown (10YR 4/4 m); sandy loam to sandy clay loam; weak medium prismatic land weak fine subangular blocky; friable; clear smooth boundary; strongly acid; common thin to moderately thick clay skins
BC	50-60+ 10 cm; brown to dark brown (10YR 4/3 m); loamy sand; single grained; very friable; clear smooth boundary; slightly acid to neutral
Cca	60-80 cm; brown to dark brown (10YR 4/3 m); loamy sand; single grained; very friable; mild alkaline; moderately effervescent

Long-Term Soil Acidification Monitoring Site

Site: Twin Butte

Location: S.E. 31 – 4 – 29 – W4; S.W. 4 – 5 – 29 – W4

Site Description: Loamy and clayey morainal sediments; hummocky and inclined; gentle and moderate slopes; well drained; moderately stony; natural grassland grazing

Subgroup: Orthic Black

Generalized Profile:

LFH	1-0 cm (grass litter)
Ah	0-22 cm; black (10YR 2.5/1 m); sandy clay loam; moderate medium prismatic; weak and moderate fine and medium subangular blocky; and strong medium granular; friable; clear wavy boundary; medium acid
AB	22-25 cm; dark brown (10YR 3/3 m); clay loam; moderate medium prismatic and strong fine subangular blocky; friable; clear wavy boundary; medium acid
Bt	25-60 cm; brown to dark brown (10YR 4/3 m); clay loam; strong medium prismatic and strong medium and fine subangular blocky; slightly hard to hard; gradual wavy boundary; medium to slightly acid; many moderately thick dark brown (10YR 3/3 d) clay skins on ped faces
BC	60-70 cm; brown (10YR 4/2 d); clay; weak medium prismatic and moderate medium subangular blocky; slightly hard to hard; clear smooth boundary; slightly acid to neutral
Cca	70-95 cm; grayish brown to dark grayish brown (2.5YR 5/2 to 4/2 d); clay; amorphous; slightly hard to hard; strongly alkaline; strongly effervescent

Long-Term Soil Acidification Monitoring Site

Site: Fort Saskatchewan

Location: S.E. 22 – 56- 21 – W4

Site Description: Sandy eolian; ridged and hummocky; moderate slopes; very rapidly drained; pine woodland

Subgroup: Eluviated Dystric Brunisol

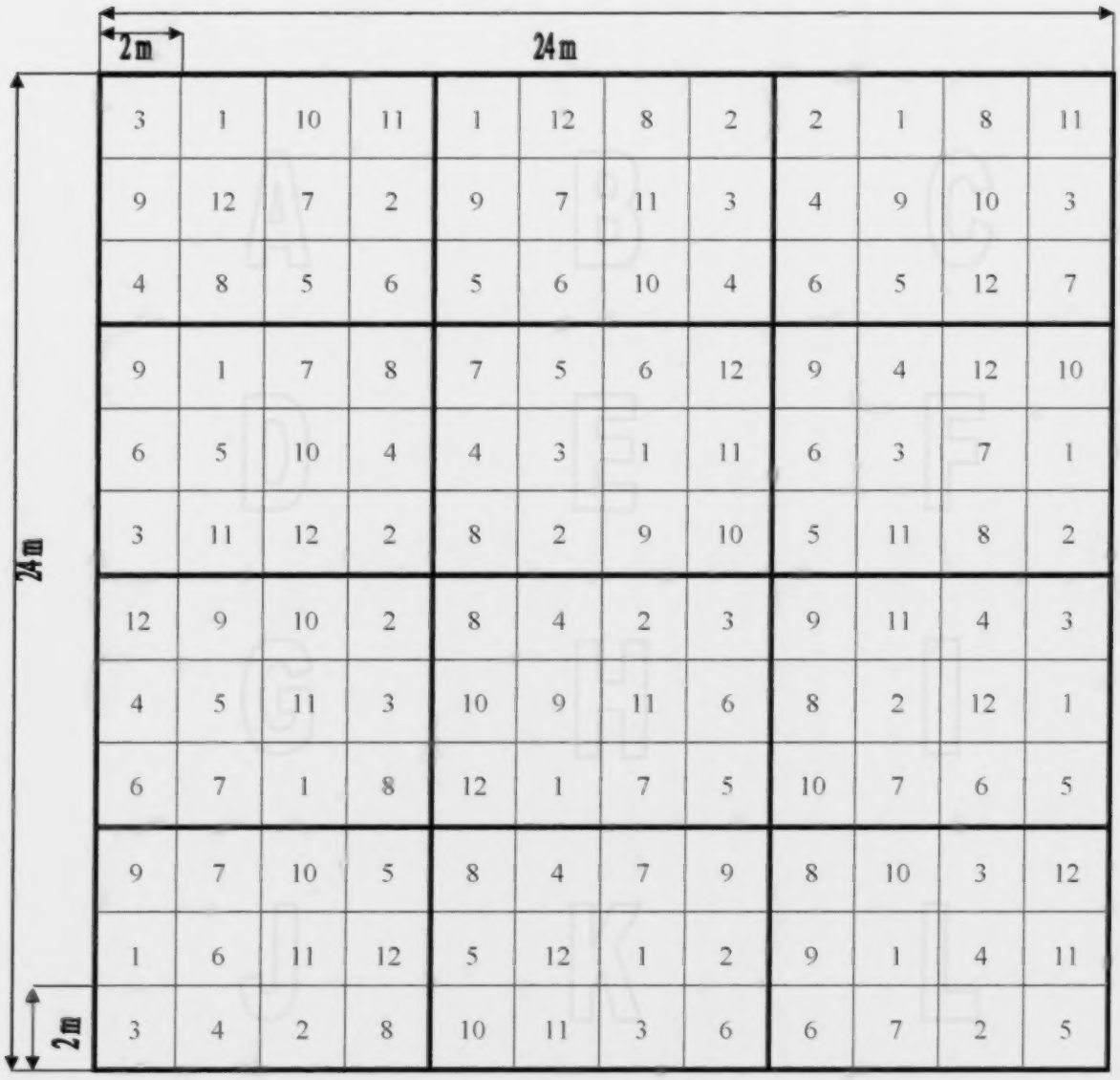
Generalized Profile [z]:

LFH	3-0 cm; very dark grayish brown (10YR 3/2, dry) with mixed brown, gray and black; needle and lichen litter; abrupt, wavy boundary; plentiful fine, horizontal roots; strongly acid
Ahe	0-3 cm; dark grayish brown (10YR 4/2); sand; single grain; loose; clear, smooth boundary; plentiful, fine to coarse horizontal roots; strongly acid; intermittent or absent in places
Ae	3-12 cm; light brownish gray (10YR 6/2); sand; single grain; loose; clear, smooth boundary; plentiful, medium to coarse, horizontal and oblique roots; strongly acid
AB	12-20 cm; brown (10YR 5/3); sand; single grain; loose; clear, smooth boundary; strongly acid
Bm1	20-42 cm; yellowish brown (10YR 5/3.5); sand; single grain; loose; clear, smooth boundary; few, medium to coarse, horizontal and oblique roots; medium acidic
Bm2	42-80 cm; yellowish brown (10YR 5/4); sand; single grain; loose; clear, smooth boundary; very few roots; medium acidic
Bm3	80-100 cm; light yellowish brown (10YR 6/4); sand; single grain; loose; roots scarce; medium acidic

[z] The soil profile description is based on modal values derived from data for twelve soil pits at each of the two sub-sites. The south sub-site differed from the north site in that it did not have an Ahe horizon. The Ahe was present in seven of the twelve soil pits in the north sub-site.

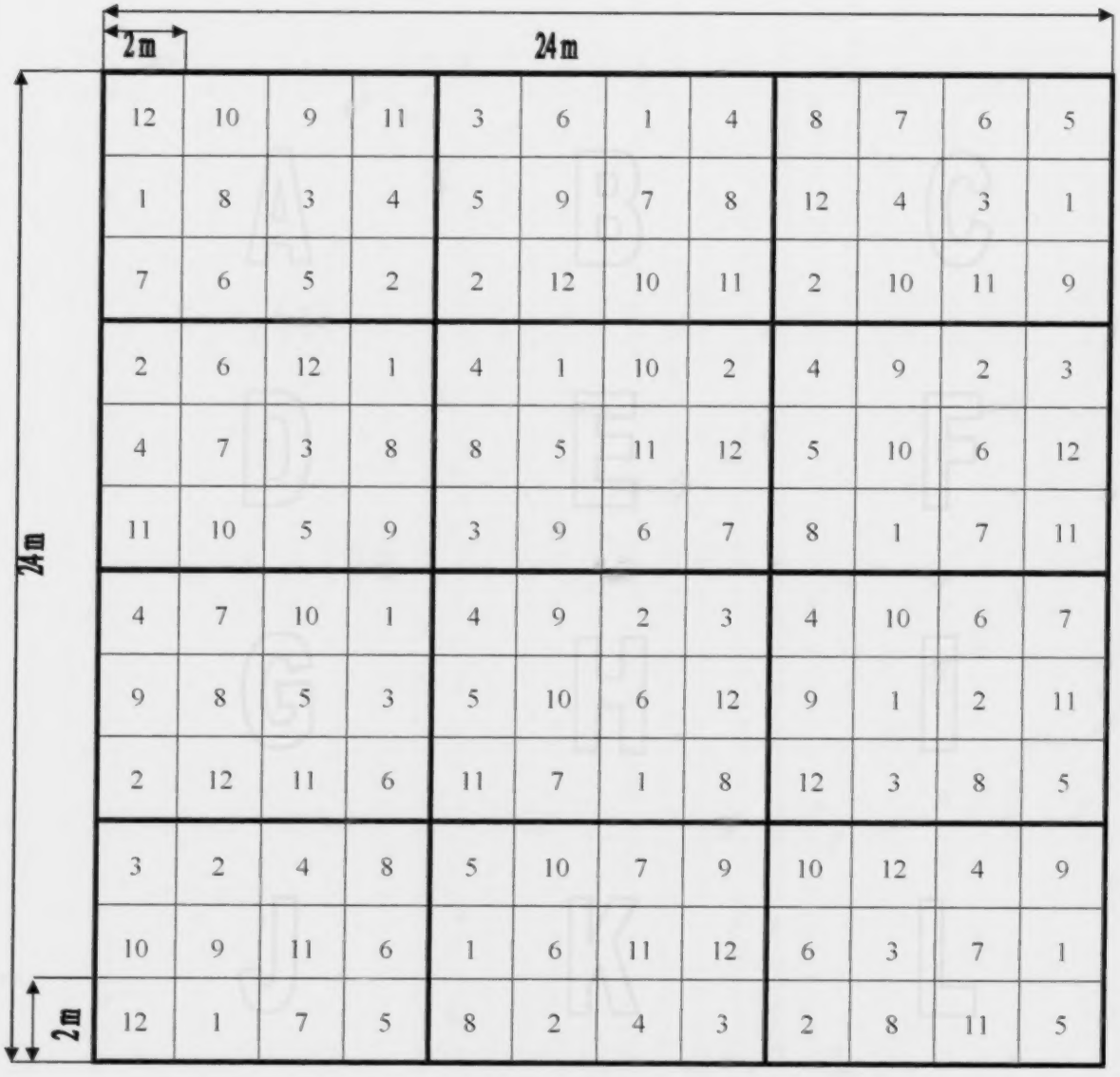
APPENDIX B

PLOT LAYOUT AND SAMPLING DESIGN



Site Name	Legal Description	Date Started
LTSAM Bruderheim - East	NW 20-56-20-W4th	1984

Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1984	5	2003	9	
2	1988	6	2007	10	
3	1992	7		11	
4	1996	8		12	



Site Name	Legal Description	Date Started
LTSAM Bruderheim - West	NW 20-56-20-W4th	1984

Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
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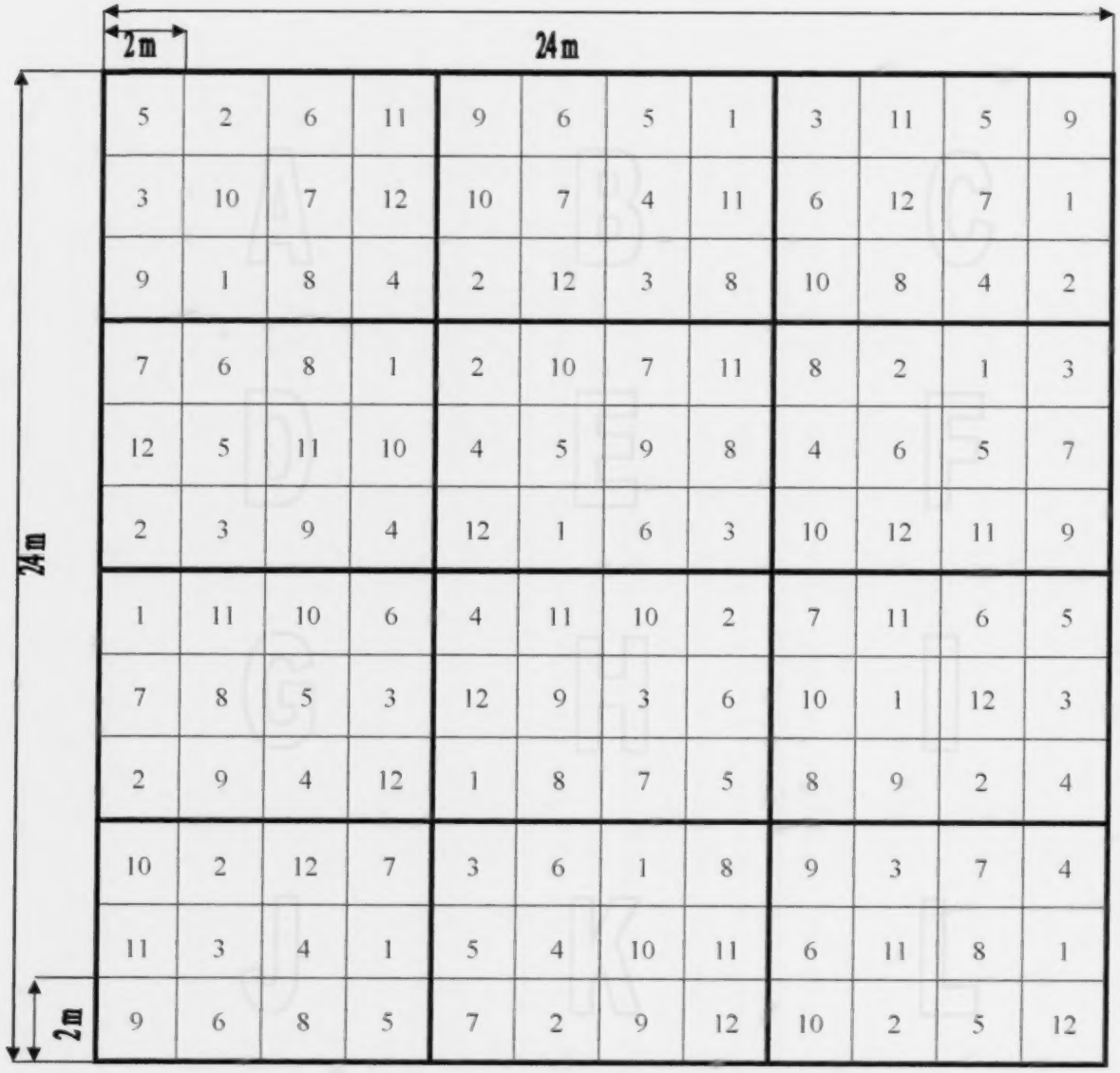
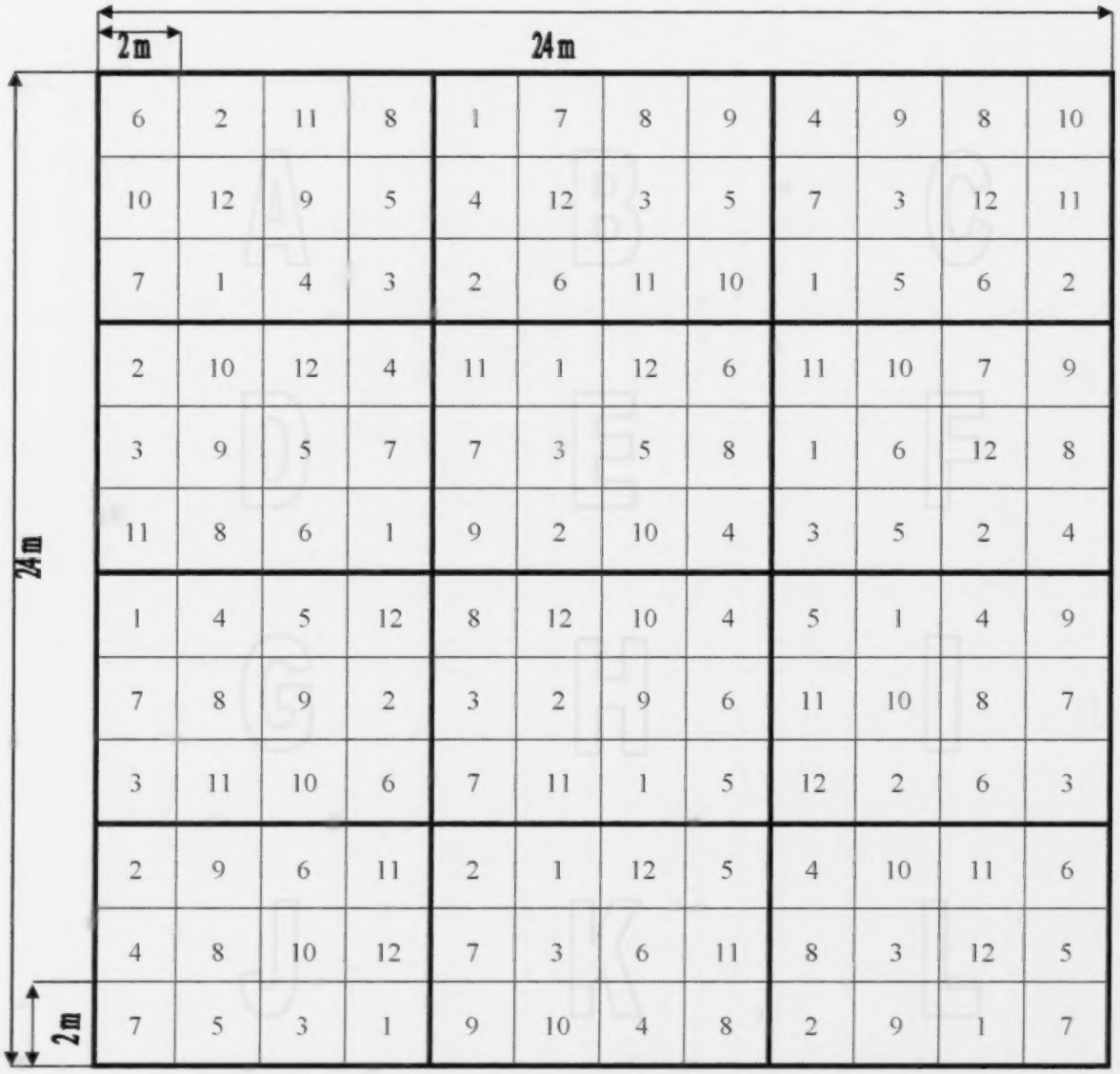
2	1988	6	2007	10	
3	1992	7		11	
4	1996	8		12	



5	2	6	11	9	6	5	1	3	11	5	9
3	10	7	12	10	7	4	11	6	12	7	1
9	1	8	4	2	12	3	8	10	8	4	2
7	6	8	1	2	10	7	11	8	2	1	3
12	5	11	10	4	5	9	8	4	6	5	7
2	3	9	4	12	1	6	3	10	12	11	9
1	11	10	6	4	11	10	2	7	11	6	5
7	8	5	3	12	9	3	6	10	1	12	3
2	9	4	12	1	8	7	5	8	9	2	4
10	2	12	7	3	6	1	8	9	3	7	4
11	3	4	1	5	4	10	11	6	11	8	1
9	6	8	5	7	2	9	12	10	2	5	12

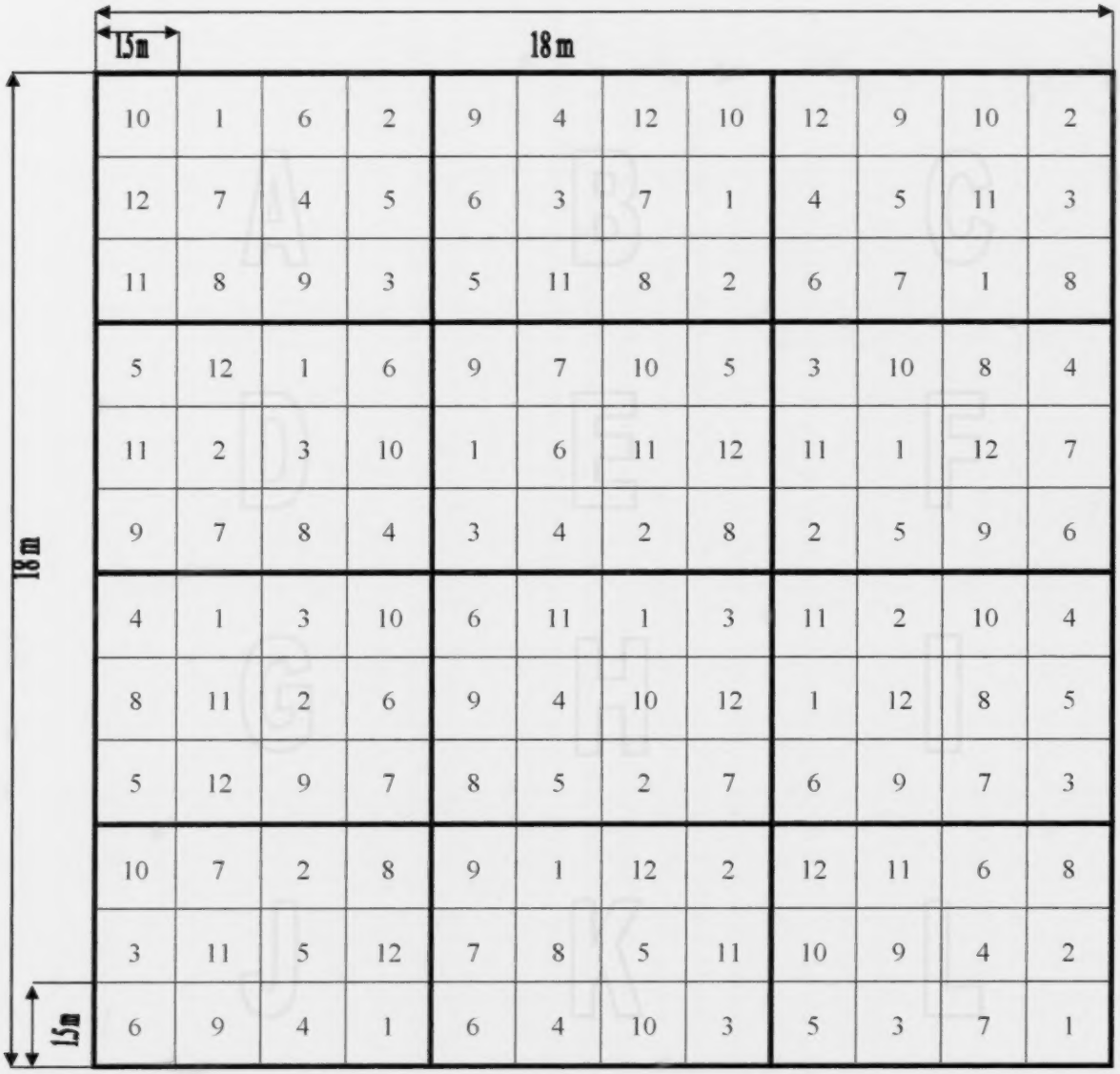
Site Name	Legal Description	Date Started
LTSAM Cold Lake - West	NW 20, SW 29-64-2-W4th	1982

Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1982	5	2001	9	
2	1986	6	2005	10	
3	1990.	7	2009	11	
4	1994	8		12	



Site Name	Legal Description	Date Started
LTSAM Cold Lake - East	NW 20, SW 29-64-2-W4th	1982

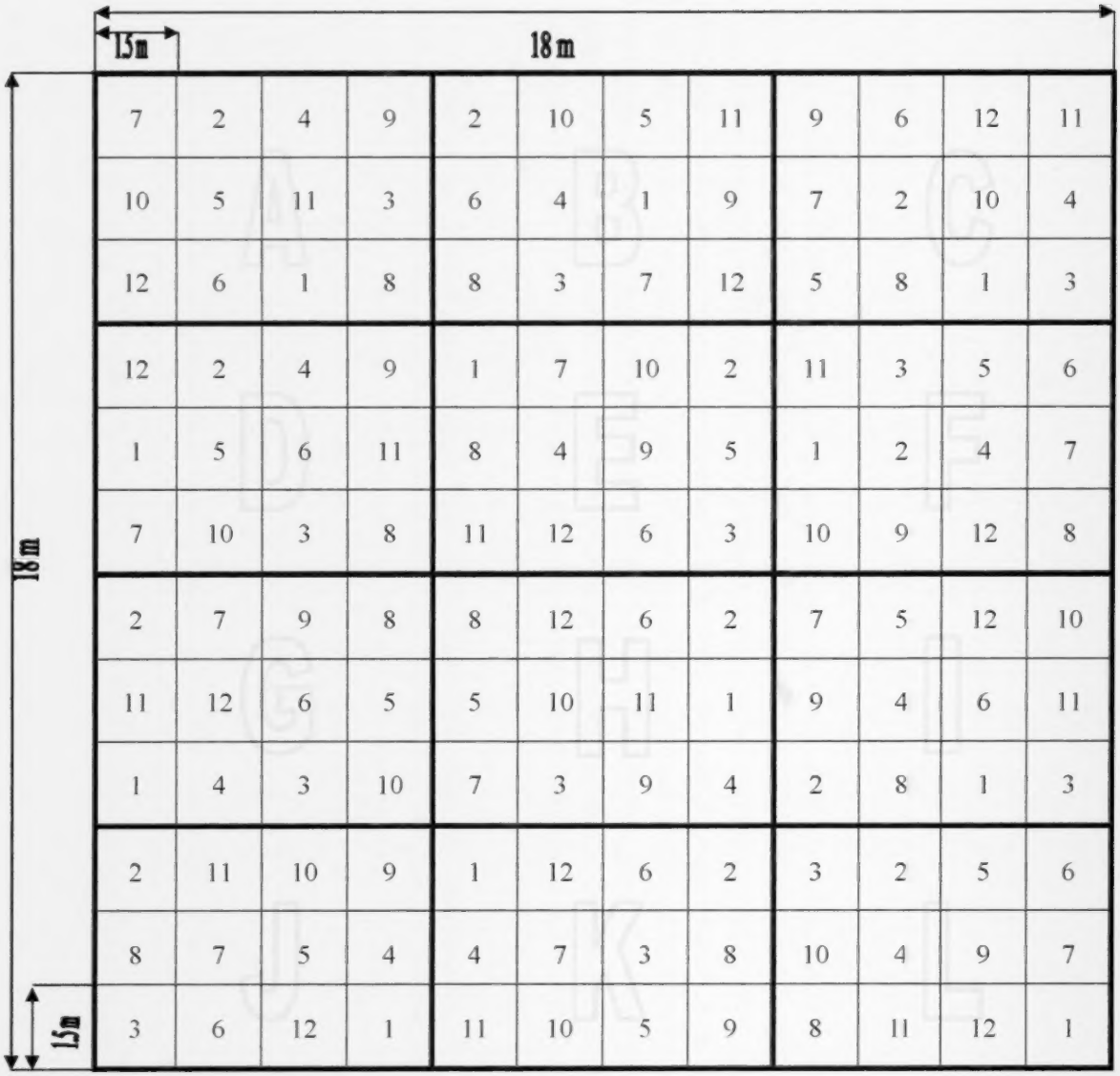
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1982	5	2001	9	
2	1986	6	2005	10	
3	1990	7	2009	11	
4	1994	8		12	



10	1	6	2	9	4	12	10	12	9	10	2
12	7	4	5	6	3	7	1	4	5	11	3
11	8	9	3	5	11	8	2	6	7	1	8
5	12	1	6	9	7	10	5	3	10	8	4
11	2	3	10	1	6	11	12	11	1	12	7
9	7	8	4	3	4	2	8	2	5	9	6
4	1	3	10	6	11	1	3	11	2	10	4
8	11	2	6	9	4	10	12	1	12	8	5
5	12	9	7	8	5	2	7	6	9	7	3
10	7	2	8	9	1	12	2	12	11	6	8
3	11	5	12	7	8	5	11	10	9	4	2
6	9	4	1	6	4	10	3	5	3	7	1

Site Name	Legal Description	Date Started
LTSAM Devon - South	SW 15-51-26-W4th	1984

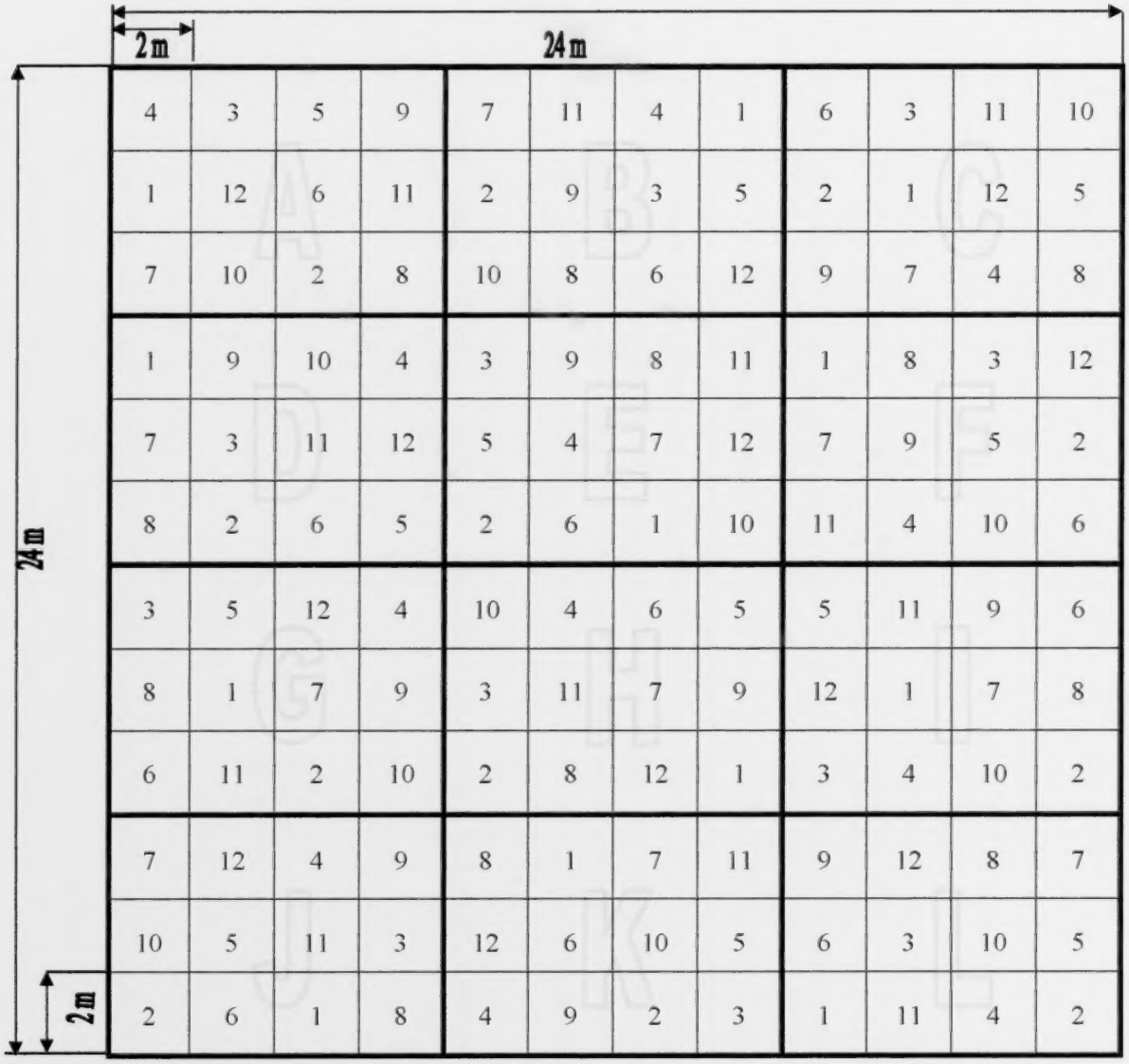
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1984	5	2003	9	
2	1988	6	2008	10	
3	1992	7		11	
4	1996	8		12	



7	2	4	9	2	10	5	11	9	6	12	11
10	5	11	3	6	4	1	9	7	2	10	4
12	6	1	8	8	3	7	12	5	8	1	3
12	2	4	9	1	7	10	2	11	3	5	6
1	5	6	11	8	4	9	5	1	2	4	7
7	10	3	8	11	12	6	3	10	9	12	8
2	7	9	8	8	12	6	2	7	5	12	10
11	12	6	5	5	10	11	1	9	4	6	11
1	4	3	10	7	3	9	4	2	8	1	3
2	11	10	9	1	12	6	2	3	2	5	6
8	7	5	4	4	7	3	8	10	4	9	7
3	6	12	1	11	10	5	9	8	11	12	1

Site Name	Legal Description	Date Started
LTSAM Devon - North	SW 15-51-26-W4th	1984

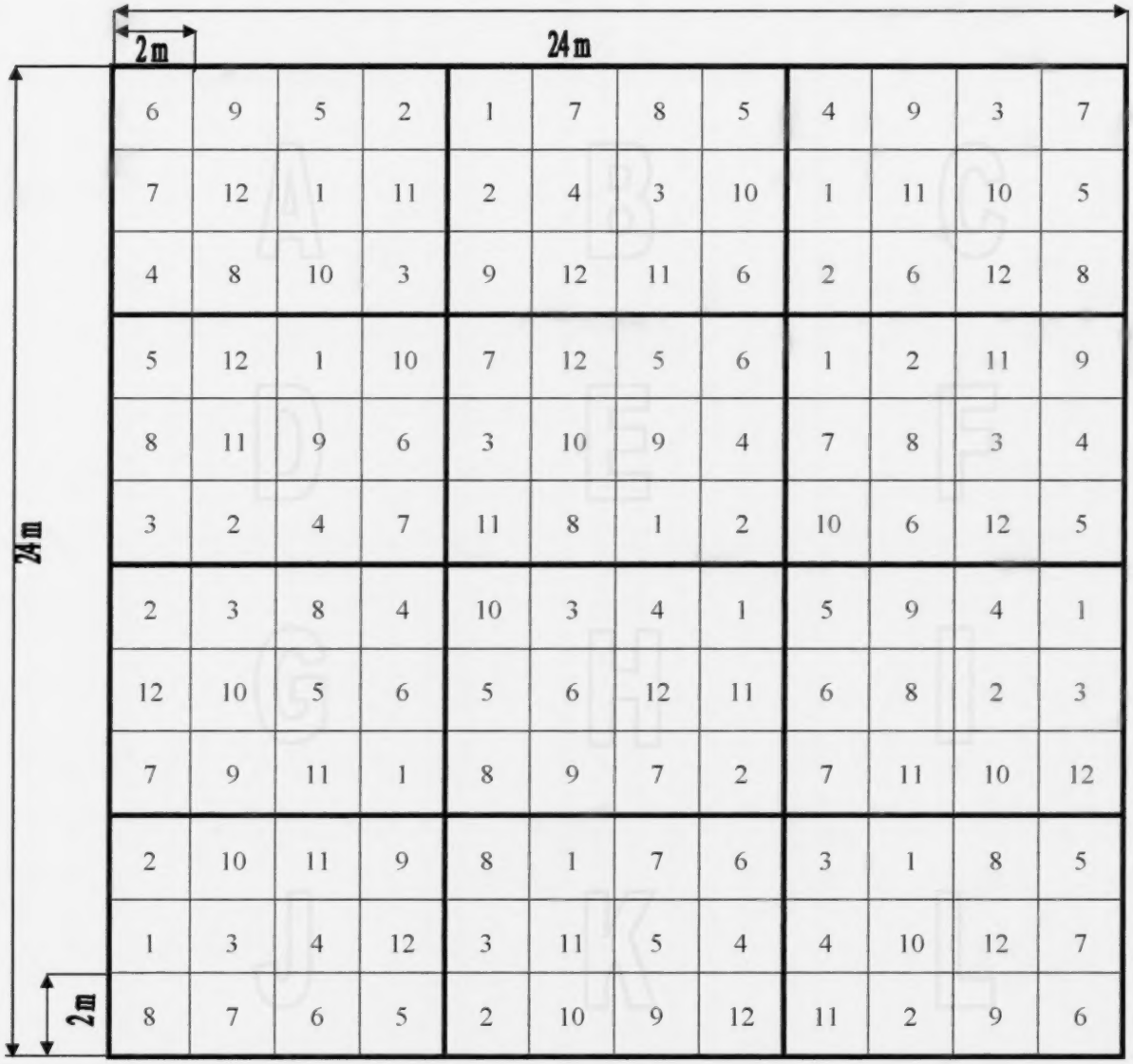
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1984	5	2003	9	
2	1988	6	2008	10	
3	1992	7		11	
4	1996	8		12	



4	3	5	9	7	11	4	1	6	3	11	10
1	12	6	11	2	9	3	5	2	1	12	5
7	10	2	8	10	8	6	12	9	7	4	8
1	9	10	4	3	9	8	11	1	8	3	12
7	3	11	12	5	4	7	12	7	9	5	2
8	2	6	5	2	6	1	10	11	4	10	6
3	5	12	4	10	4	6	5	5	11	9	6
8	1	7	9	3	11	7	9	12	1	7	8
6	11	2	10	2	8	12	1	3	4	10	2
7	12	4	9	8	1	7	11	9	12	8	7
10	5	11	3	12	6	10	5	6	3	10	5
2	6	1	8	4	9	2	3	1	11	4	2

Site Name	Legal Description	Date Started
LTSAM Esther - North	SE 33-31-2-W4th	1983

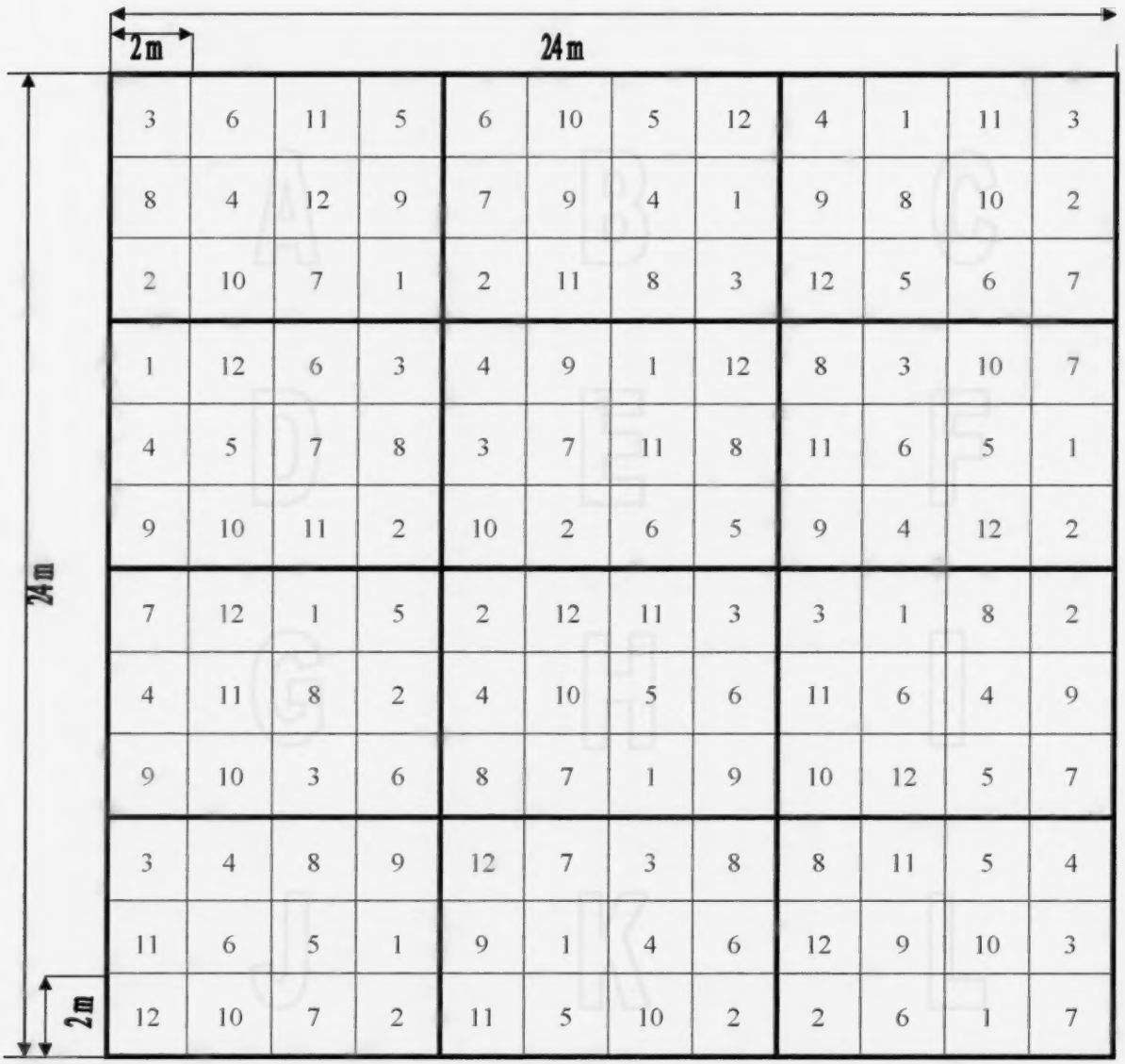
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1983	5	2002	9	
2	1987	6	2007	10	
3	1991	7		11	
4	1995	8		12	



6	9	5	2	1	7	8	5	4	9	3	7
7	12	1	11	2	4	3	10	1	11	10	5
4	8	10	3	9	12	11	6	2	6	12	8
5	12	1	10	7	12	5	6	1	2	11	9
8	11	9	6	3	10	9	4	7	8	3	4
3	2	4	7	11	8	1	2	10	6	12	5
2	3	8	4	10	3	4	1	5	9	4	1
12	10	5	6	5	6	12	11	6	8	2	3
7	9	11	1	8	9	7	2	7	11	10	12
2	10	11	9	8	1	7	6	3	1	8	5
1	3	4	12	3	11	5	4	4	10	12	7
8	7	6	5	2	10	9	12	11	2	9	6

Site Name	Legal Description	Date Started
LTSAM Esther - South	SE 33-31-2-W4th	1983

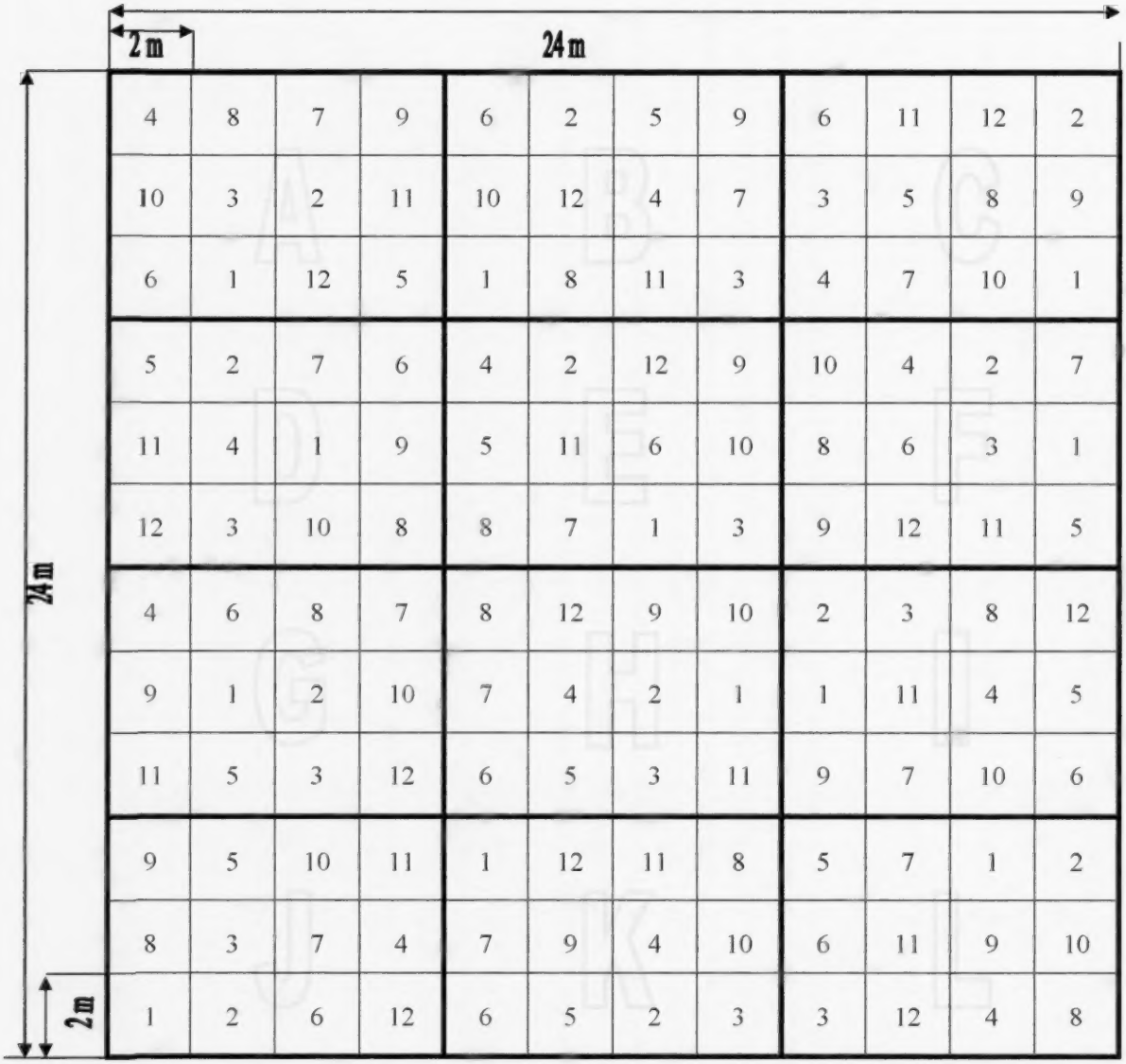
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1983	5	2002	9	
2	1987	6	2007	10	
3	1991	7		11	
4	1995	8		12	



3	6	11	5	6	10	5	12	4	1	11	3
8	4	12	9	7	9	4	1	9	8	10	2
2	10	7	1	2	11	8	3	12	5	6	7
1	12	6	3	4	9	1	12	8	3	10	7
4	5	7	8	3	7	11	8	11	6	5	1
9	10	11	2	10	2	6	5	9	4	12	2
7	12	1	5	2	12	11	3	3	1	8	2
4	11	8	2	4	10	5	6	11	6	4	9
9	10	3	6	8	7	1	9	10	12	5	7
3	4	8	9	12	7	3	8	8	11	5	4
11	6	5	1	9	1	4	6	12	9	10	3
12	10	7	2	11	5	10	2	2	6	1	7

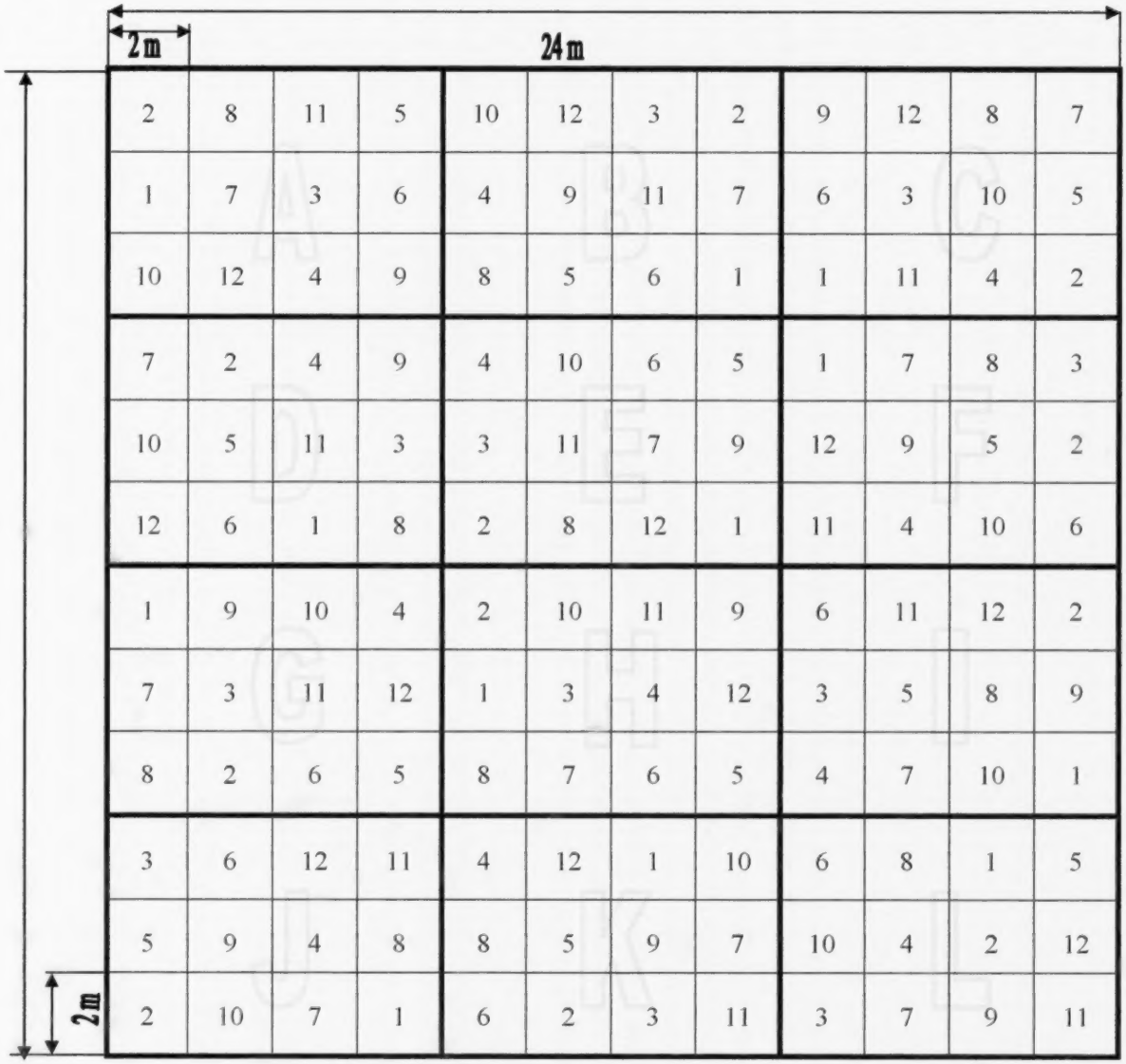
Site Name	Legal Description	Date Started
LTSAM High Prairie - West	NE 33-75-17-W5th	1983

Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1983	5	2002	9	
2	1987	6	2006	10	
3	1991	7	2010	11	
4	1995	8		12	



Site Name	Legal Description	Date Started
LTSAM High Prairie - East	NW 34-75-17-W5th	1983

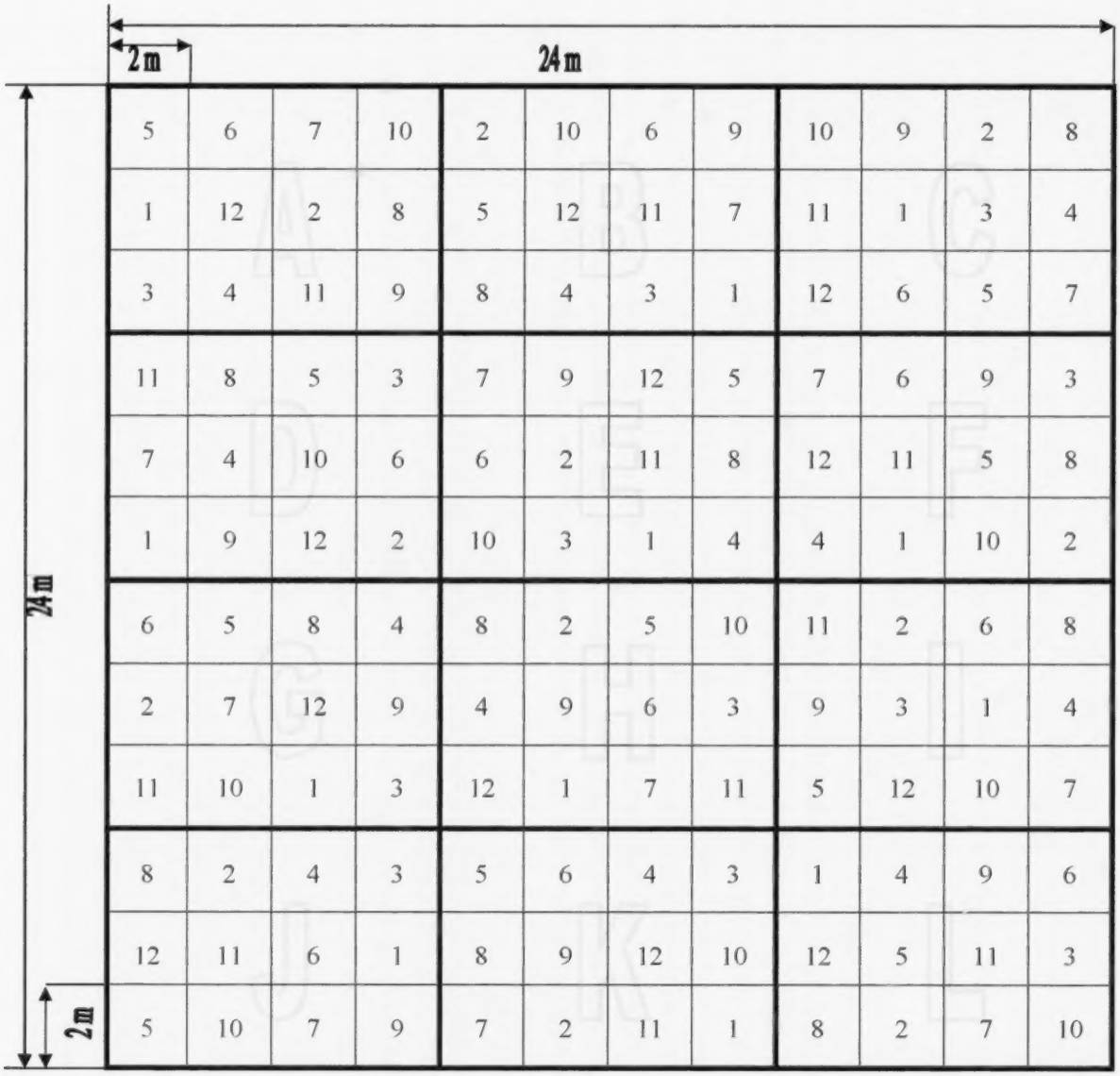
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1983	5	2002	9	
2	1987	6	2006	10	
3	1991	7	2010	11	
4	1995	8		12	



2	8	11	5	10	12	3	2	9	12	8	7
1	7	3	6	4	9	11	7	6	3	10	5
10	12	4	9	8	5	6	1	1	11	4	2
7	2	4	9	4	10	6	5	1	7	8	3
10	5	11	3	3	11	7	9	12	9	5	2
12	6	1	8	2	8	12	1	11	4	10	6
1	9	10	4	2	10	11	9	6	11	12	2
7	3	11	12	1	3	4	12	3	5	8	9
8	2	6	5	8	7	6	5	4	7	10	1
3	6	12	11	4	12	1	10	6	8	1	5
5	9	4	8	8	5	9	7	10	4	2	12
2	10	7	1	6	2	3	11	3	7	9	11

Site Name	Legal Description	Date Started
LTSAM Rocky Mountain House - North	NW 11-38-8-W5th	1981

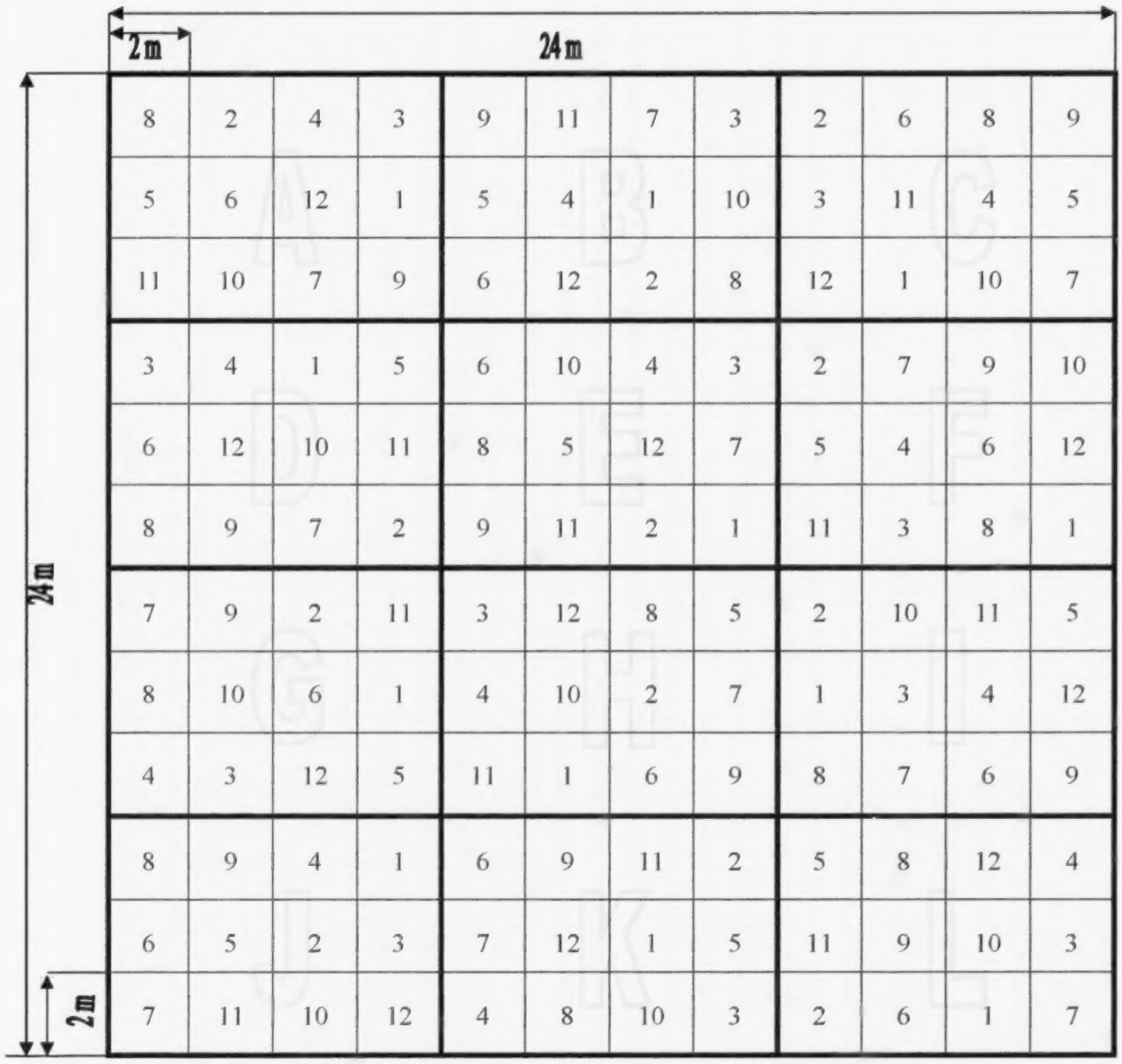
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1981	5	2000	9	
2	1985	6	2005	10	
3	1989	7	2009	11	
4	1993	8		12	



5	6	7	10	2	10	6	9	10	9	2	8
1	12	2	8	5	12	11	7	11	1	3	4
3	4	11	9	8	4	3	1	12	6	5	7
11	8	5	3	7	9	12	5	7	6	9	3
7	4	10	6	6	2	11	8	12	11	5	8
1	9	12	2	10	3	1	4	4	1	10	2
6	5	8	4	8	2	5	10	11	2	6	8
2	7	12	9	4	9	6	3	9	3	1	4
11	10	1	3	12	1	7	11	5	12	10	7
8	2	4	3	5	6	4	3	1	4	9	6
12	11	6	1	8	9	12	10	12	5	11	3
5	10	7	9	7	2	11	1	8	2	7	10

Site Name	Legal Description	Date Started
LTSAM Rocky Mountain House - South	NW 11-38-8-W5th	1981

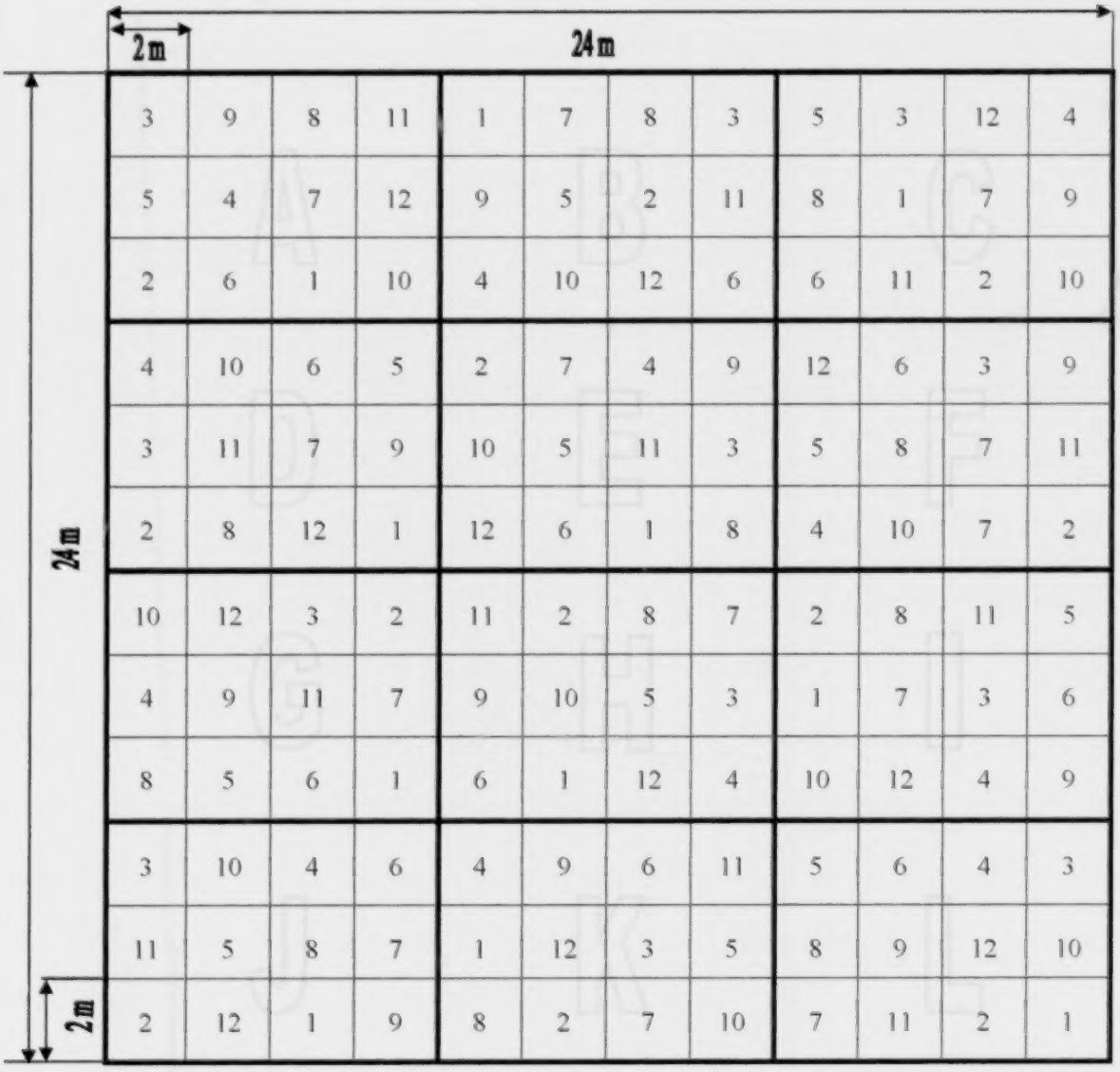
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1981	5	2000	9	
2	1985	6	2005	10	
3	1989	7	2009	11	
4	1993	8		12	



8	2	4	3	9	11	7	3	2	6	8	9
5	6	12	1	5	4	1	10	3	11	4	5
11	10	7	9	6	12	2	8	12	1	10	7
3	4	1	5	6	10	4	3	2	7	9	10
6	12	10	11	8	5	12	7	5	4	6	12
8	9	7	2	9	11	2	1	11	3	8	1
7	9	2	11	3	12	8	5	2	10	11	5
8	10	6	1	4	10	2	7	1	3	4	12
4	3	12	5	11	1	6	9	8	7	6	9
8	9	4	1	6	9	11	2	5	8	12	4
6	5	2	3	7	12	1	5	11	9	10	3
7	11	10	12	4	8	10	3	2	6	1	7

Site Name	Legal Description	Date Started
LTSAM Twin Butte - West	SE 31-4-29-W4th	1982

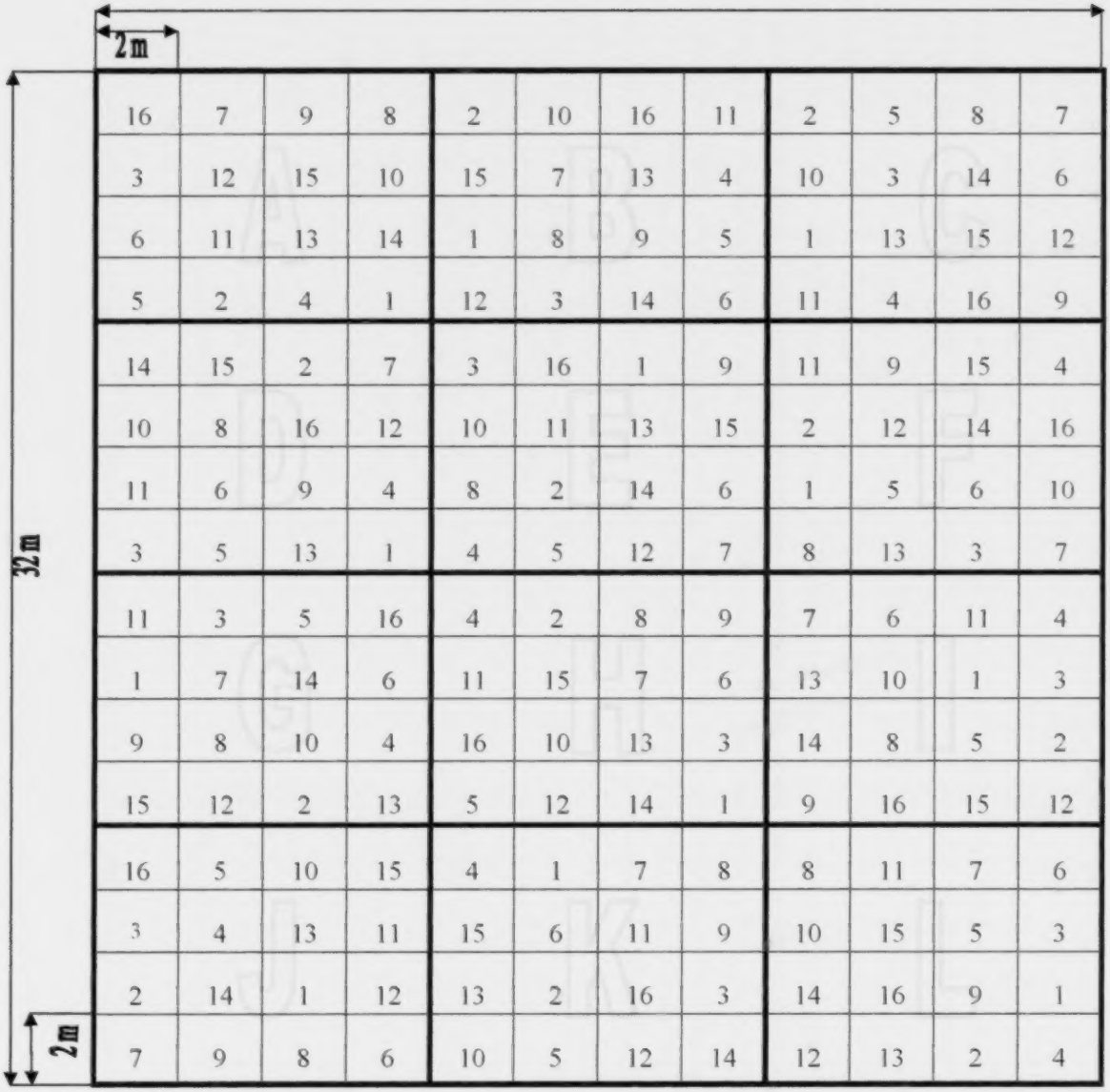
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1982	5	2001	9	
2	1986	6	2006	10	
3	1990	7		11	
4	1994	8		12	



3	9	8	11	1	7	8	3	5	3	12	4
5	4	7	12	9	5	2	11	8	1	7	9
2	6	1	10	4	10	12	6	6	11	2	10
4	10	6	5	2	7	4	9	12	6	3	9
3	11	7	9	10	5	11	3	5	8	7	11
2	8	12	1	12	6	1	8	4	10	7	2
10	12	3	2	11	2	8	7	2	8	11	5
4	9	11	7	9	10	5	3	1	7	3	6
8	5	6	1	6	1	12	4	10	12	4	9
3	10	4	6	4	9	6	11	5	6	4	3
11	5	8	7	1	12	3	5	8	9	12	10
2	12	1	9	8	2	7	10	7	11	2	1

Site Name	Legal Description	Date Started
LTSAM Twin Butte - East	SW 4-5-29-W4th	1982

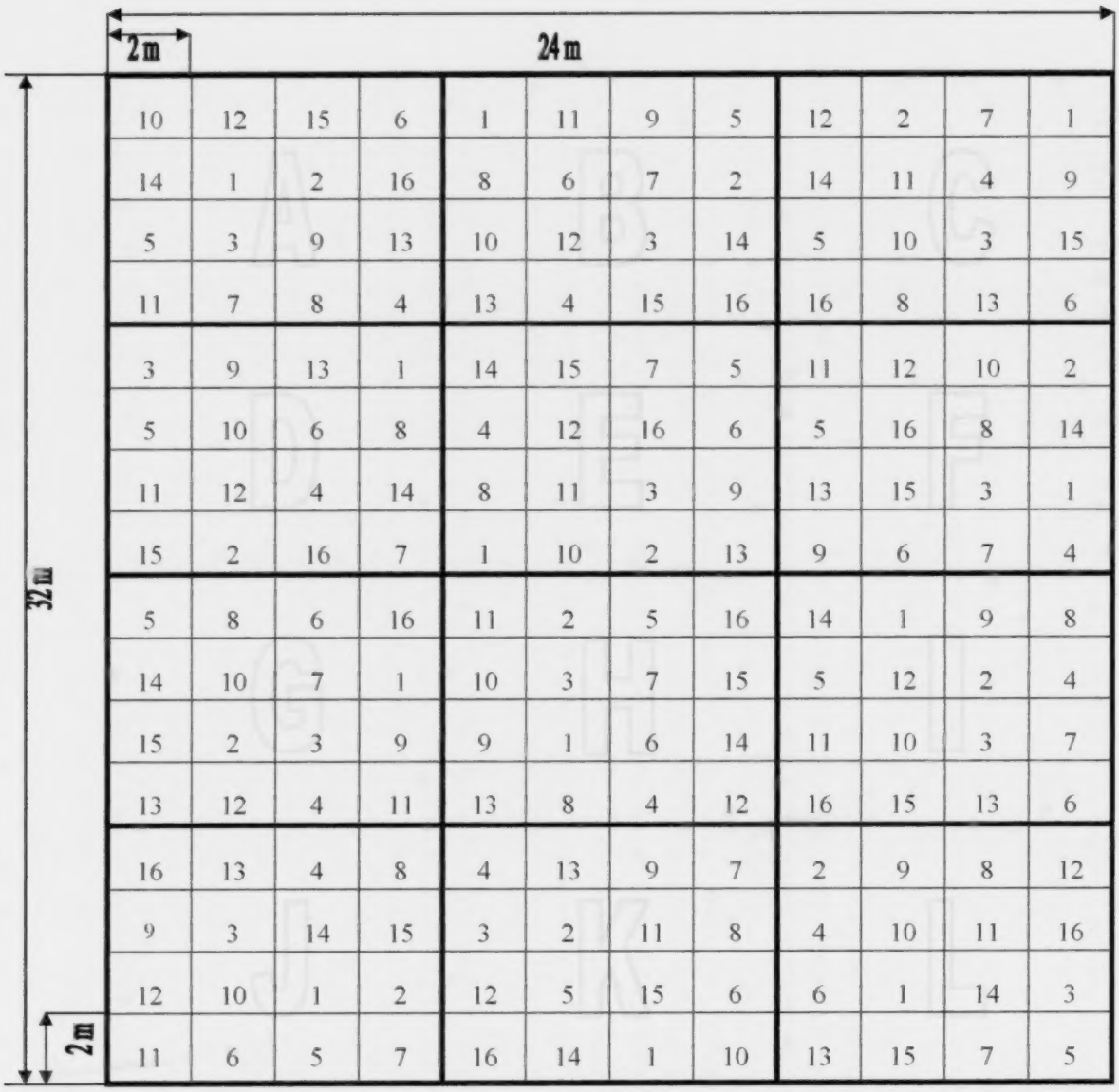
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1982	5	2001	9	
2	1986	6	2006	10	
3	1990	7		11	
4	1994	8		12	



16	7	9	8	2	10	16	11	2	5	8	7
3	12	15	10	15	7	13	4	10	3	14	6
6	11	13	14	1	8	9	5	1	13	15	12
5	2	4	1	12	3	14	6	11	4	16	9
14	15	2	7	3	16	1	9	11	9	15	4
10	8	16	12	10	11	13	15	2	12	14	16
11	6	9	4	8	2	14	6	1	5	6	10
3	5	13	1	4	5	12	7	8	13	3	7
11	3	5	16	4	2	8	9	7	6	11	4
1	7	14	6	11	15	7	6	13	10	1	3
9	8	10	4	16	10	13	3	14	8	5	2
15	12	2	13	5	12	14	1	9	16	15	12
16	5	10	15	4	1	7	8	8	11	7	6
3	4	13	11	15	6	11	9	10	15	5	3
2	14	1	12	13	2	16	3	14	16	9	1
7	9	8	6	10	5	12	14	12	13	2	4

Site Name	Legal Description	Date Started
LTSAM Fort McMurray - North	SW 5, SE 6-94-9-W4th NE 31, NW 32-93-9-W4th	1981

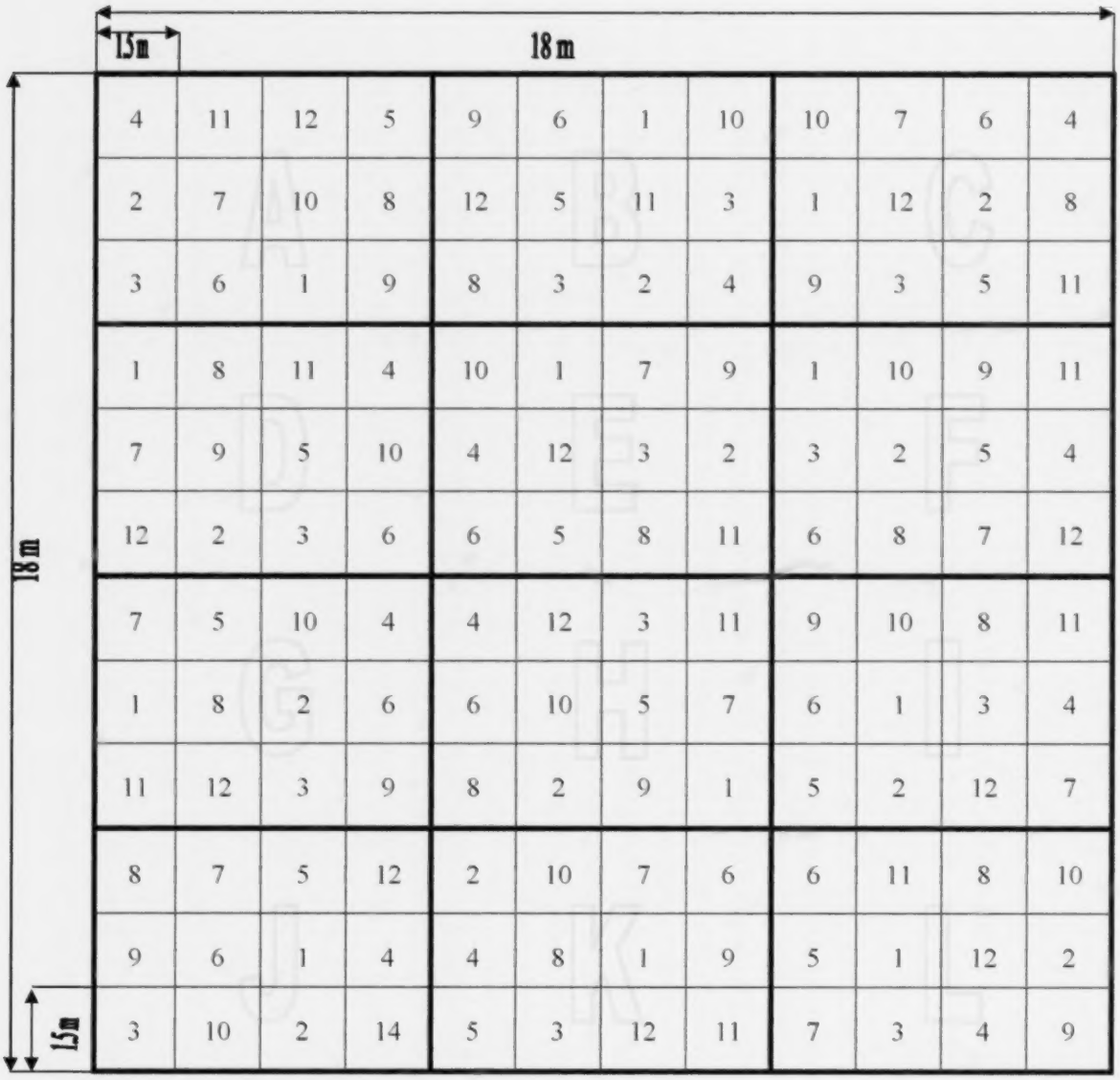
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1981	5	2004	9	
2	1985	6	2008	10	
3	1989	7		11	
4	1993	8		12	



10	12	15	6	1	11	9	5	12	2	7	1
14	1	2	16	8	6	7	2	14	11	4	9
5	3	9	13	10	12	3	14	5	10	3	15
11	7	8	4	13	4	15	16	16	8	13	6
3	9	13	1	14	15	7	5	11	12	10	2
5	10	6	8	4	12	16	6	5	16	8	14
11	12	4	14	8	11	3	9	13	15	3	1
15	2	16	7	1	10	2	13	9	6	7	4
5	8	6	16	11	2	5	16	14	1	9	8
14	10	7	1	10	3	7	15	5	12	2	4
15	2	3	9	9	1	6	14	11	10	3	7
13	12	4	11	13	8	4	12	16	15	13	6
16	13	4	8	4	13	9	7	2	9	8	12
9	3	14	15	3	2	11	8	4	10	11	16
12	10	1	2	12	5	15	6	6	1	14	3
11	6	5	7	16	14	1	10	13	15	7	5

Site Name	Legal Description	Date Started
LTSAM Fort McMurray - South	SW 5, SE 6-94-9-W4th NE 31, NW 32-93-9-W4th	1981

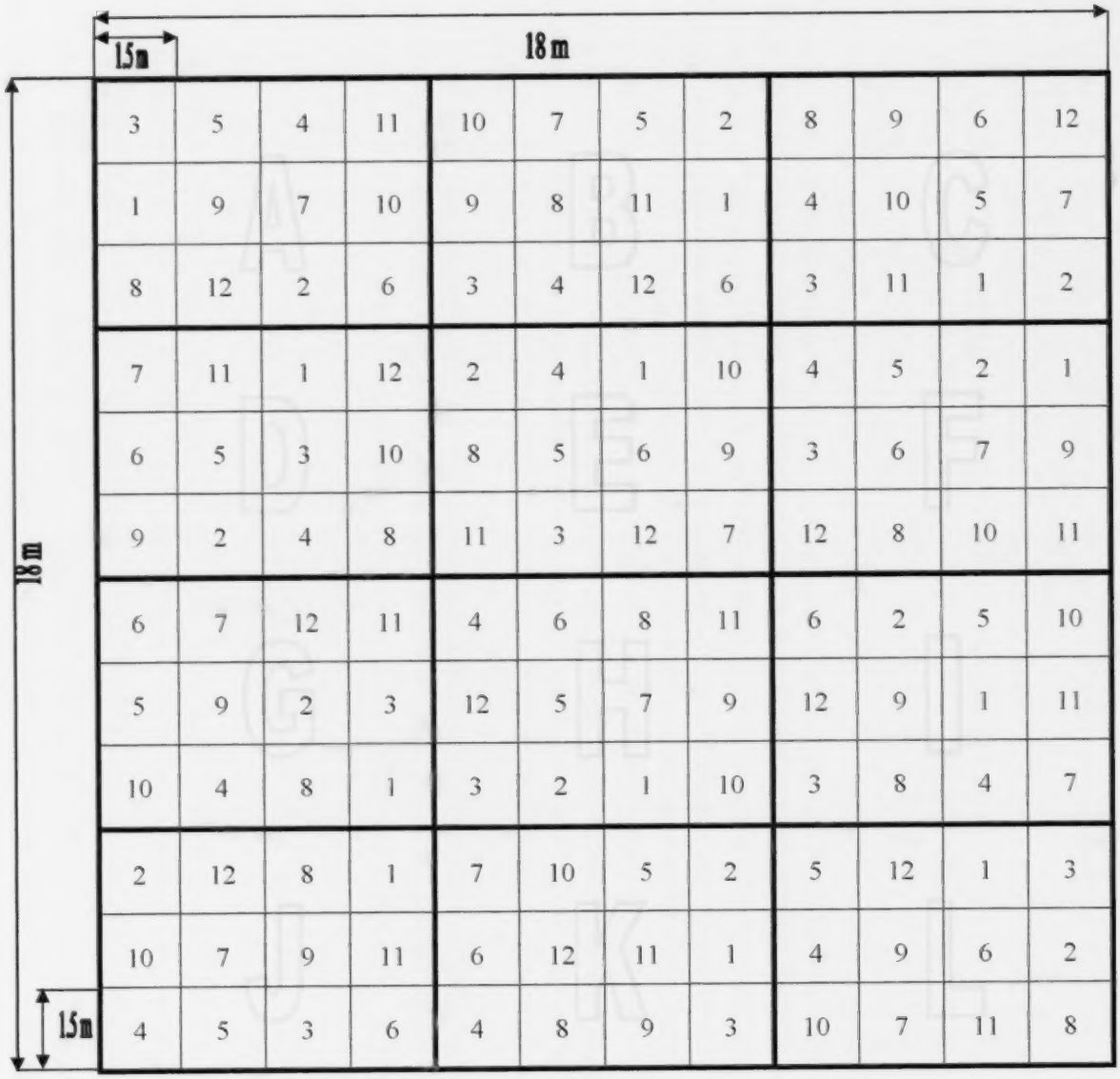
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	1981	5	2004	9	
2	1985	6	2008	10	
3	1989	7		11	
4	1993	8		12	



4	11	12	5	9	6	1	10	10	7	6	4
2	7	10	8	12	5	11	3	1	12	2	8
3	6	1	9	8	3	2	4	9	3	5	11
1	8	11	4	10	1	7	9	1	10	9	11
7	9	5	10	4	12	3	2	3	2	5	4
12	2	3	6	6	5	8	11	6	8	7	12
7	5	10	4	4	12	3	11	9	10	8	11
1	8	2	6	6	10	5	7	6	1	3	4
11	12	3	9	8	2	9	1	5	2	12	7
8	7	5	12	2	10	7	6	6	11	8	10
9	6	1	4	4	8	1	9	5	1	12	2
3	10	2	14	5	3	12	11	7	3	4	9

Site Name	Legal Description	Date Started
LTSAM FORT SASKATCHEWAN - North	SE 22-56-21-W4th	2008

Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	2008	5		9	
2	2010	6		10	
3		7		11	
4		8		12	



3	5	4	11	10	7	5	2	8	9	6	12
1	9	7	10	9	8	11	1	4	10	5	7
8	12	2	6	3	4	12	6	3	11	1	2
7	11	1	12	2	4	1	10	4	5	2	1
6	5	3	10	8	5	6	9	3	6	7	9
9	2	4	8	11	3	12	7	12	8	10	11
6	7	12	11	4	6	8	11	6	2	5	10
5	9	2	3	12	5	7	9	12	9	1	11
10	4	8	1	3	2	1	10	3	8	4	7
2	12	8	1	7	10	5	2	5	12	1	3
10	7	9	11	6	12	11	1	4	9	6	2
4	5	3	6	4	8	9	3	10	7	11	8

Site Name	Legal Description	Date Started
LTSAM FORT SASKATCHEWAN - South	SE 22-56-21-W4th	2008

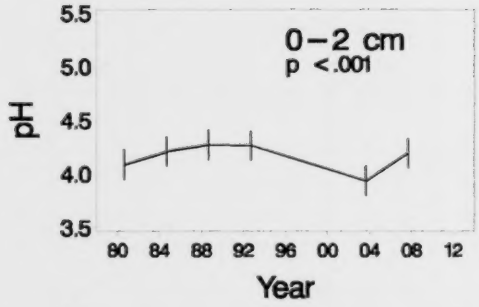
Sub-plot	Sampled	Sub-plot	Sampled	Sub-plot	Sampled
1	2008	5		9	
2	2010	6		10	
3		7		11	
4		8		12	

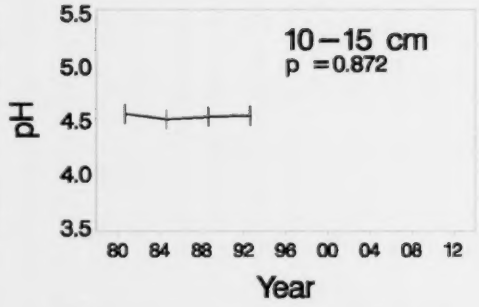
APPENDIX C

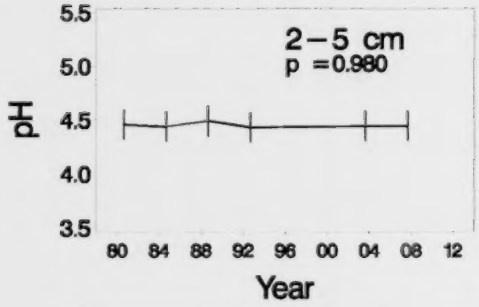
GRAPHICAL PRESENTATION OF PH, BASE SATURATION PERCENTAGE AND BASE CATION: ALUMINUM RATIO AT ALL SITES

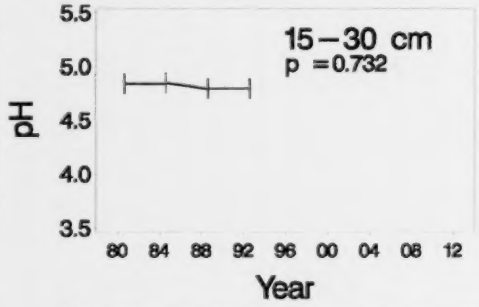
APPENDIX C1

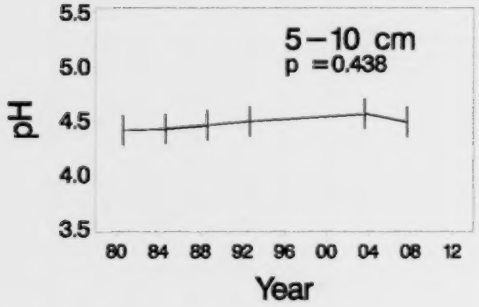
Graphical Presentation of pH ($CaCl_2$) at all Sites

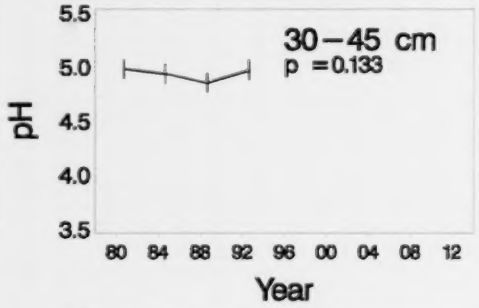




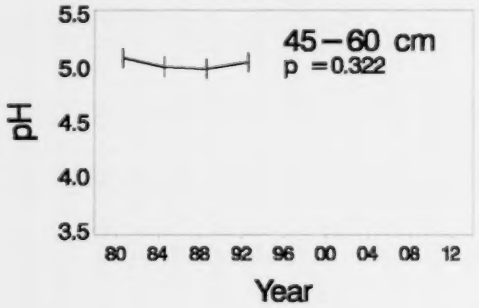




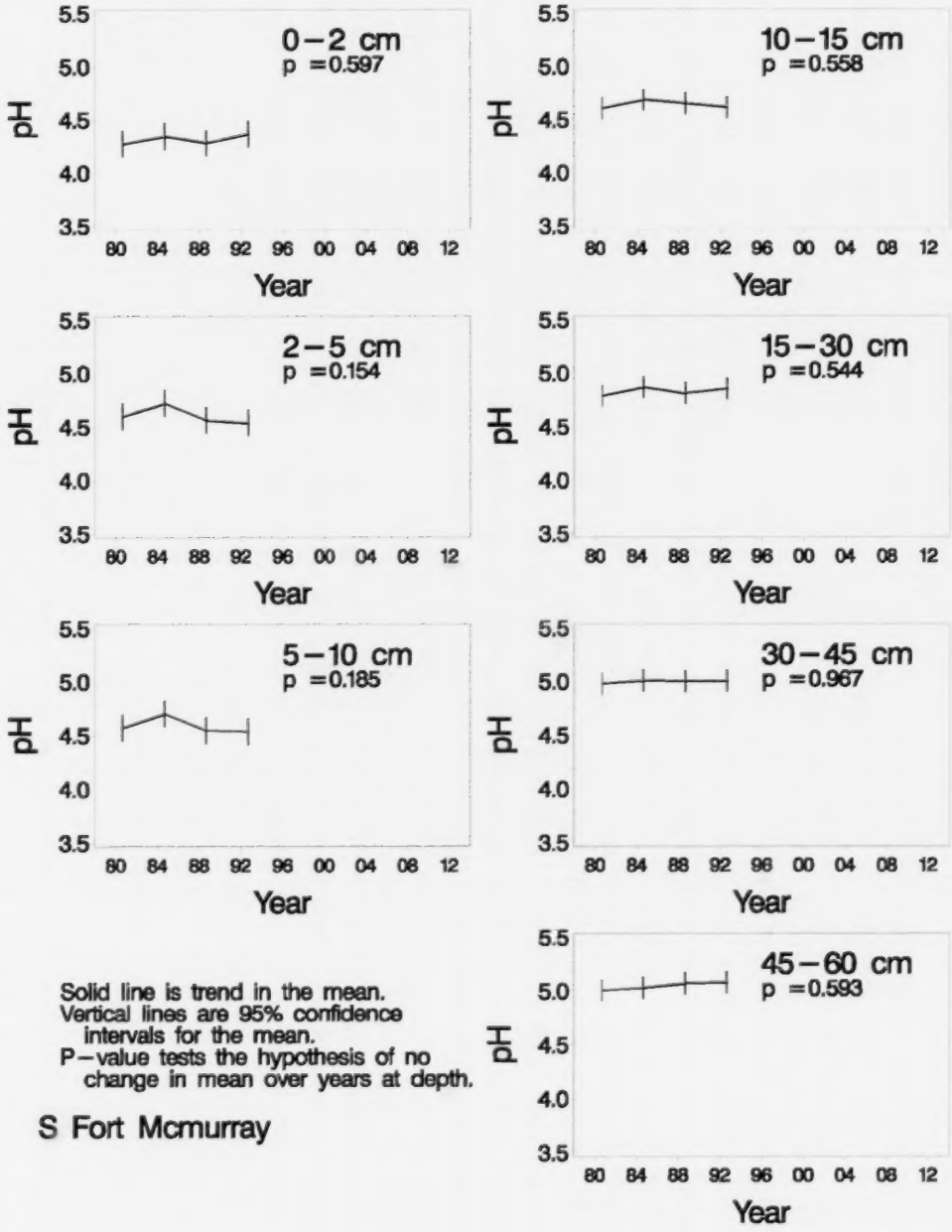




Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

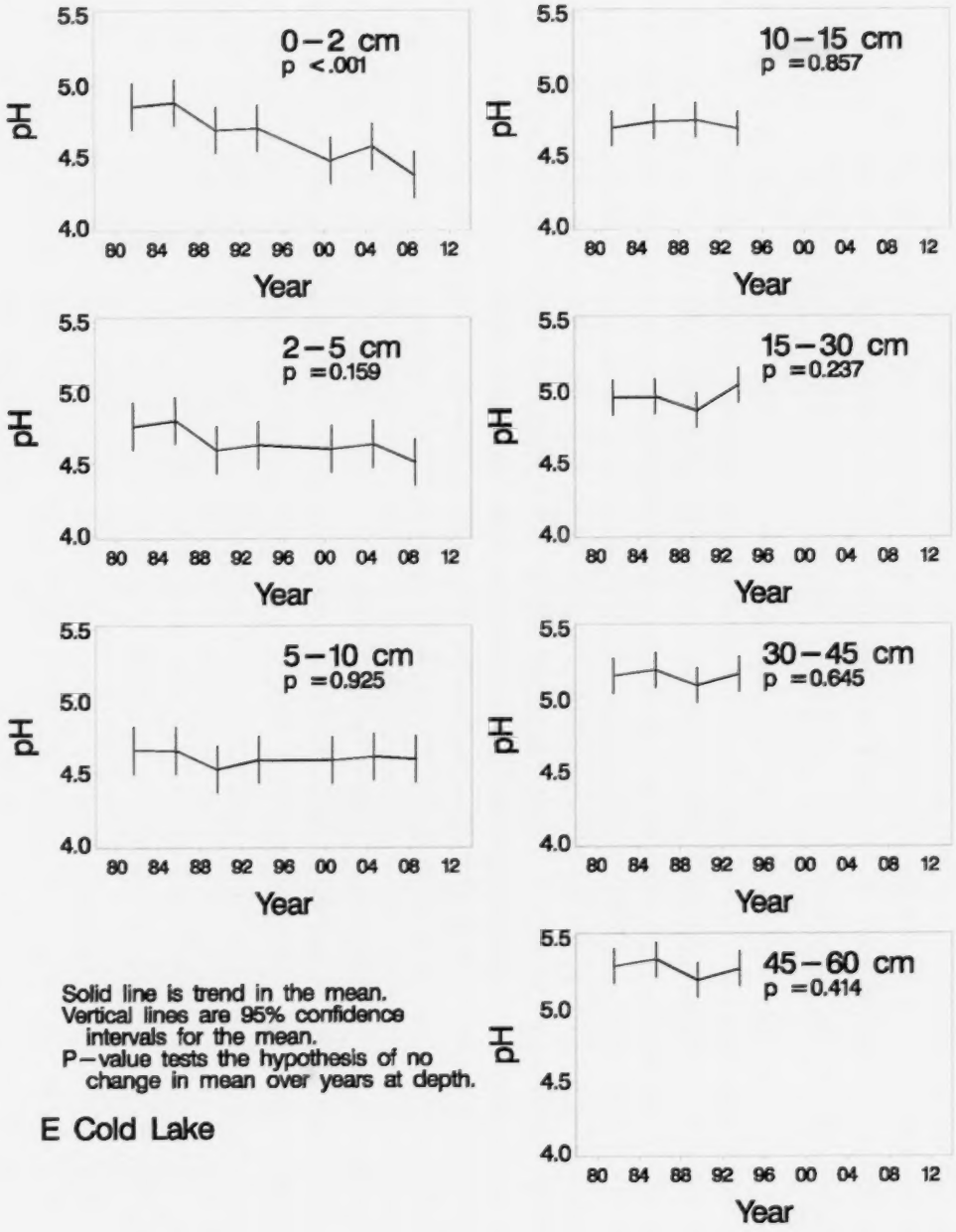


N Fort Mcmurray



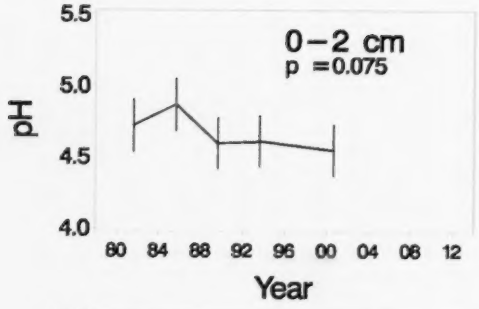
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

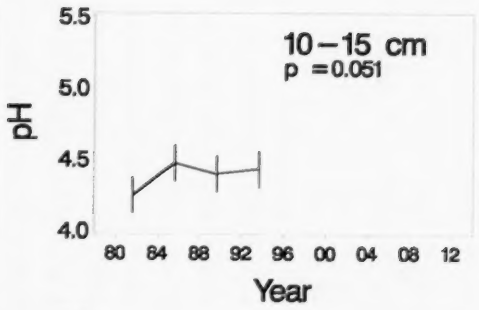
S Fort Mcmurray

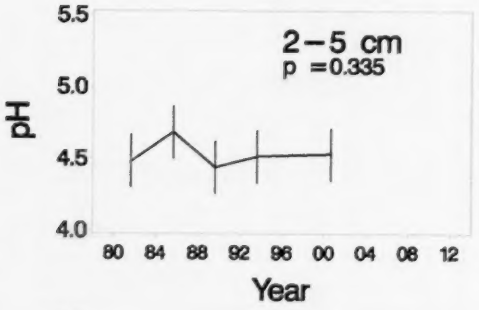


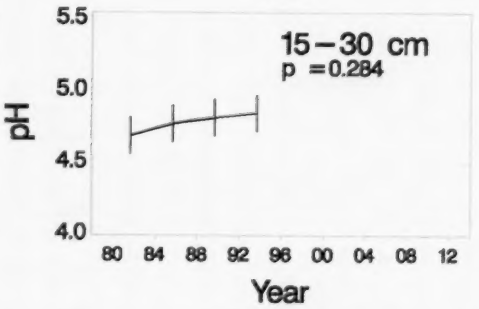
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

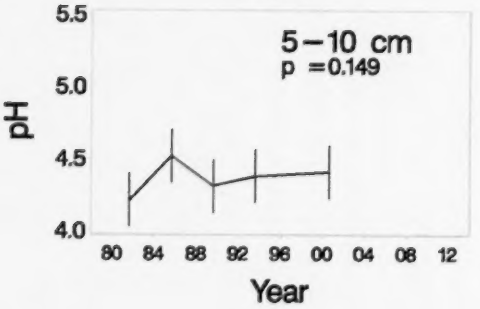
E Cold Lake

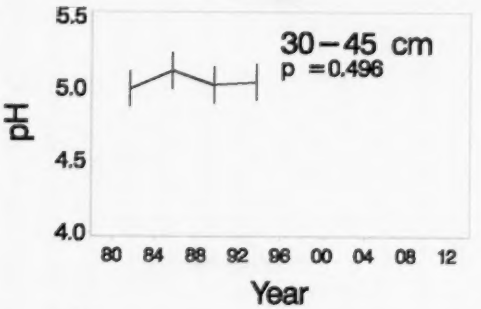


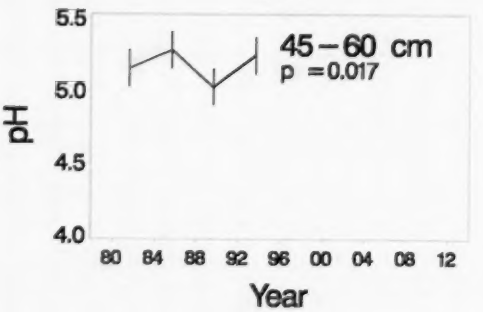












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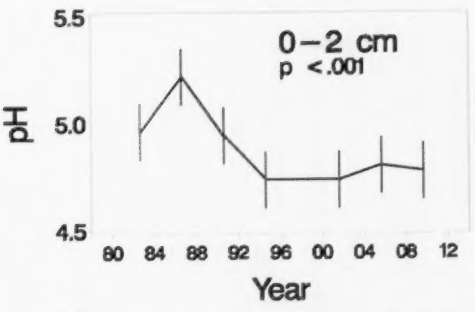
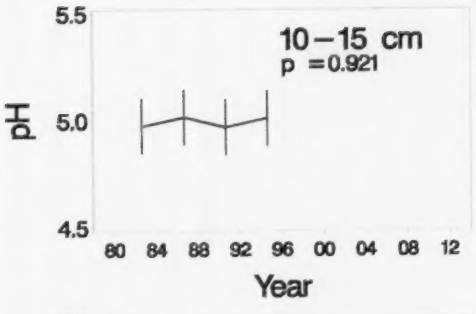
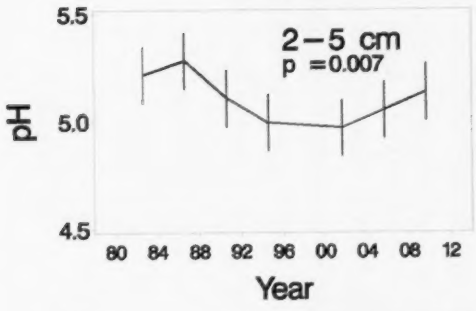
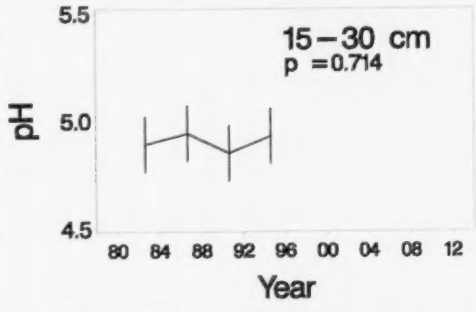
P–value tests the hypothesis of no change in mean over years at depth.

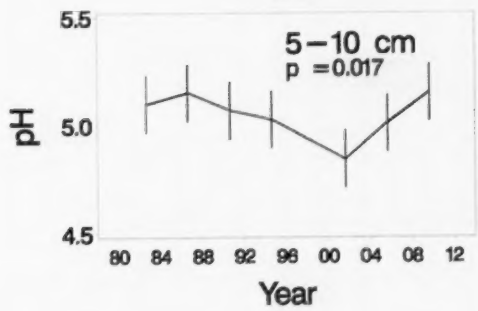
W Cold Lake

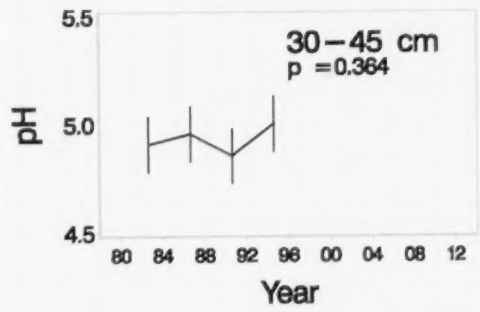


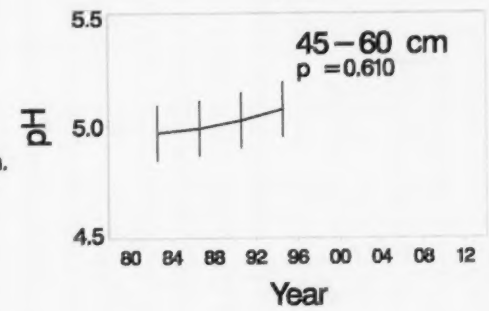












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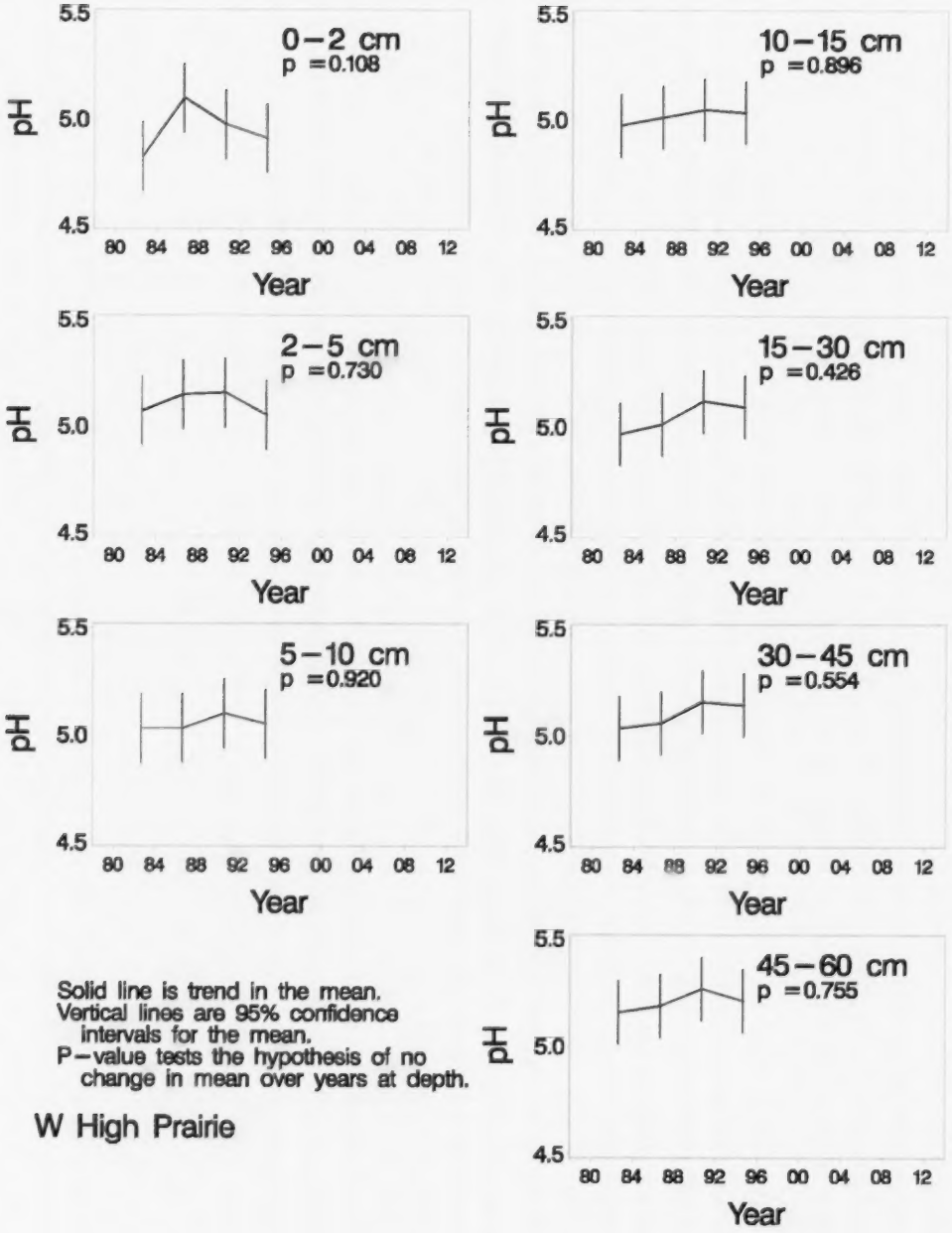
E High Prairie



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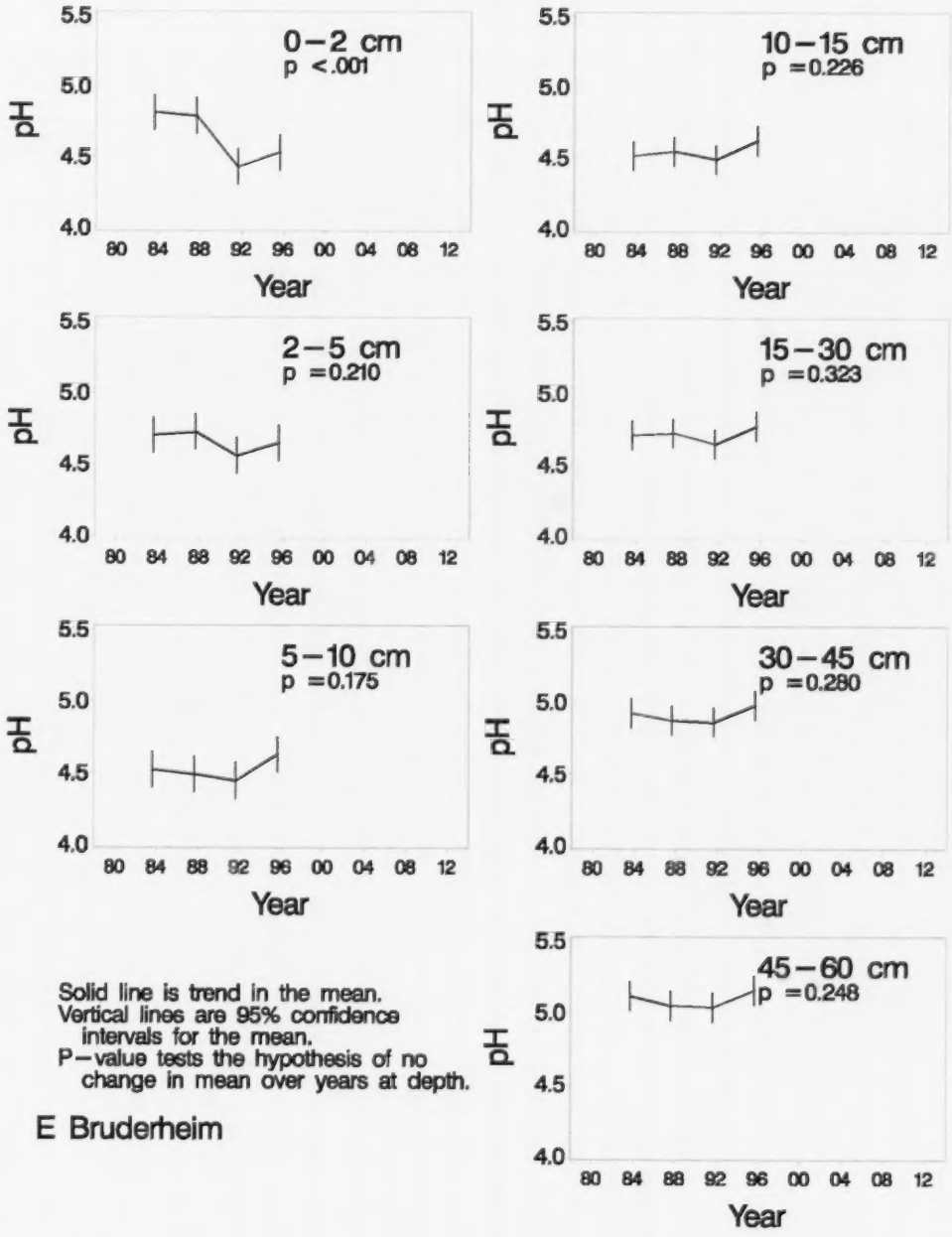
W High Prairie



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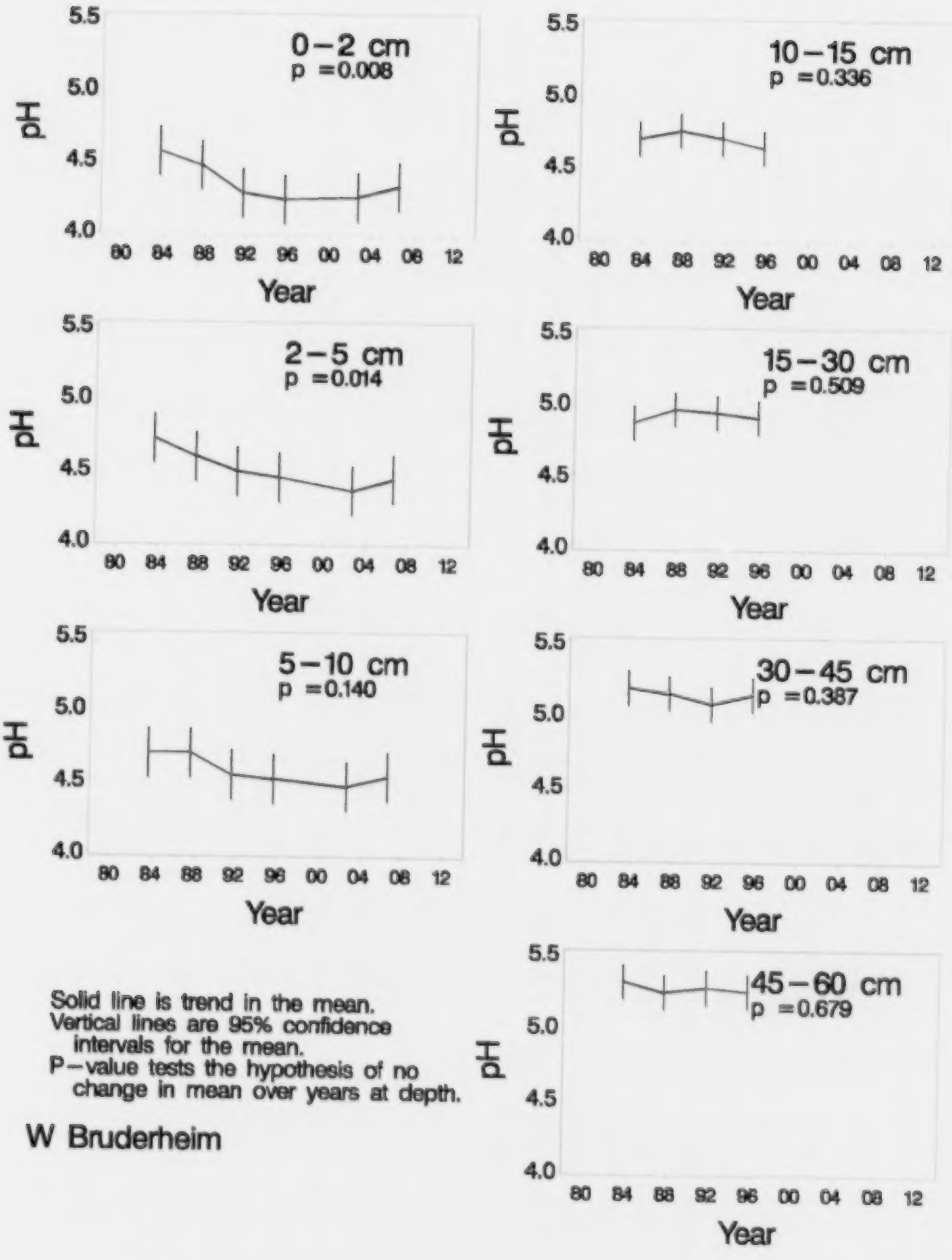
E Bruderheim



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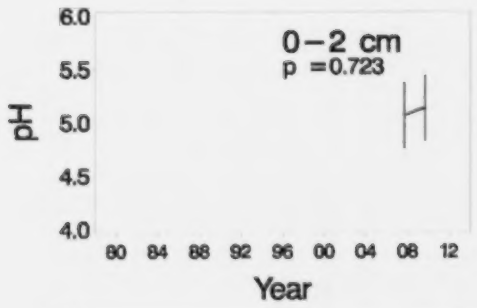
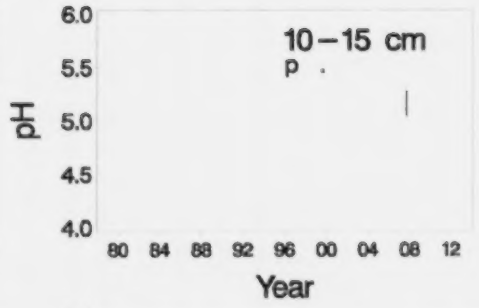
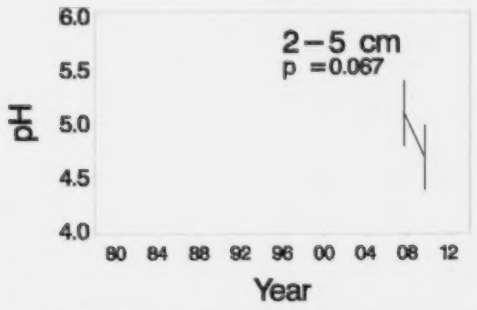
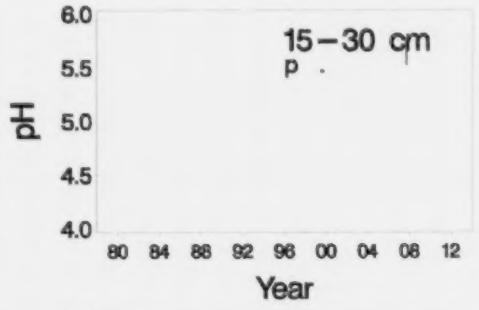
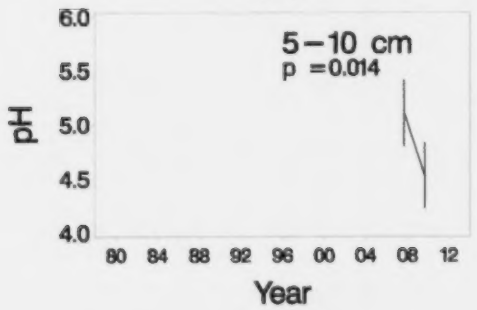
W Bruderheim

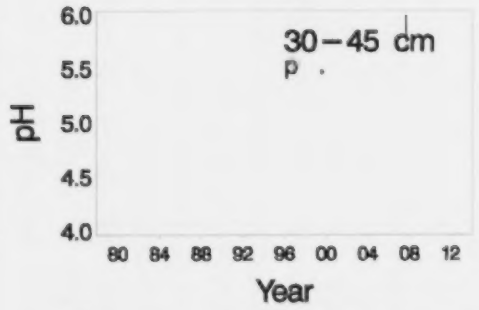


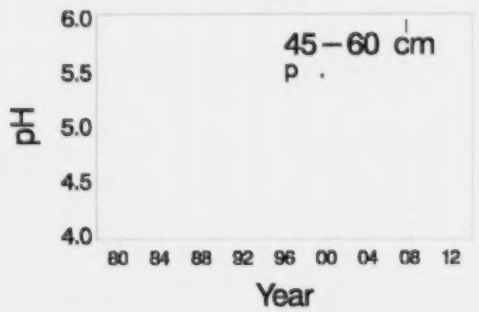












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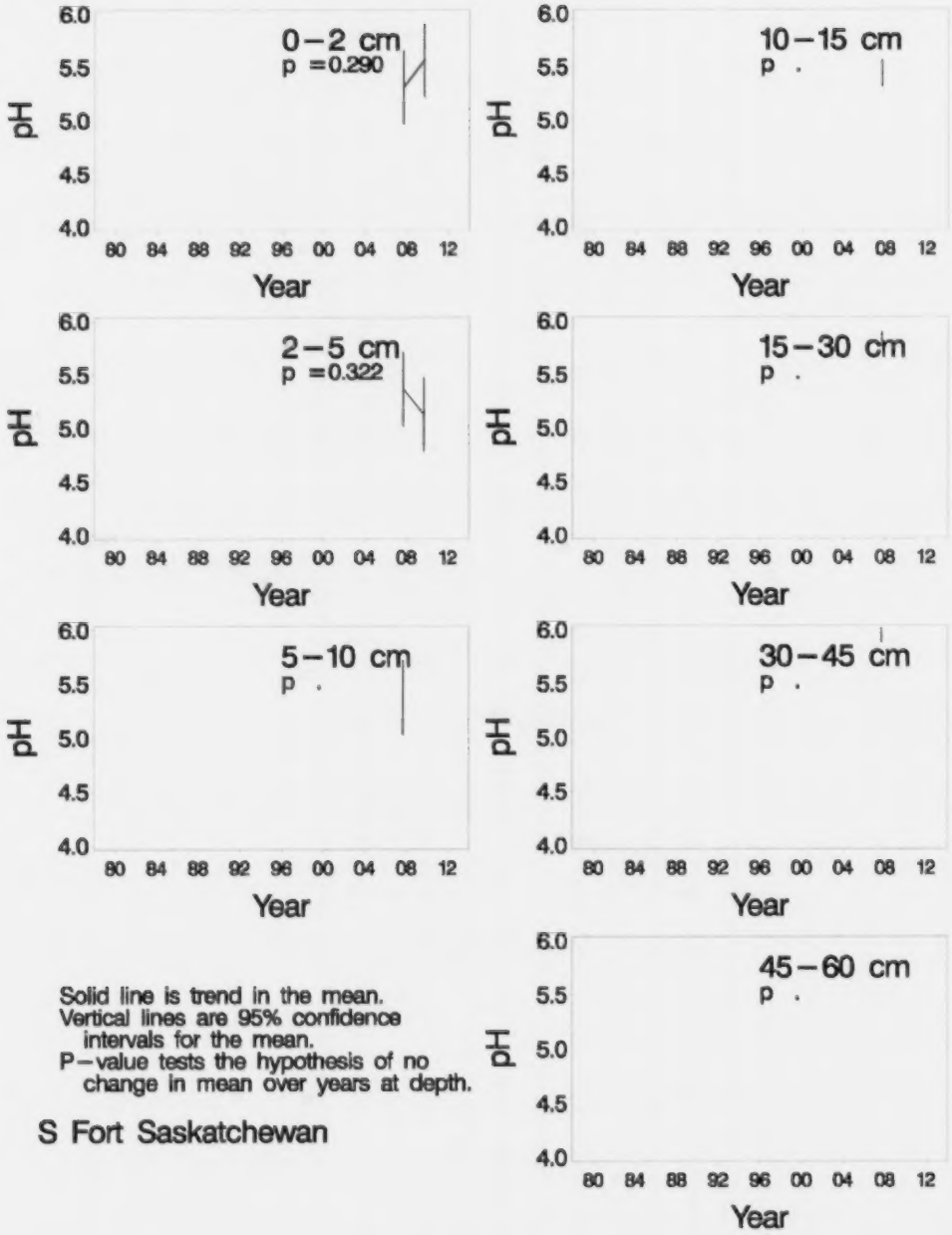
N Fort Saskatchewan



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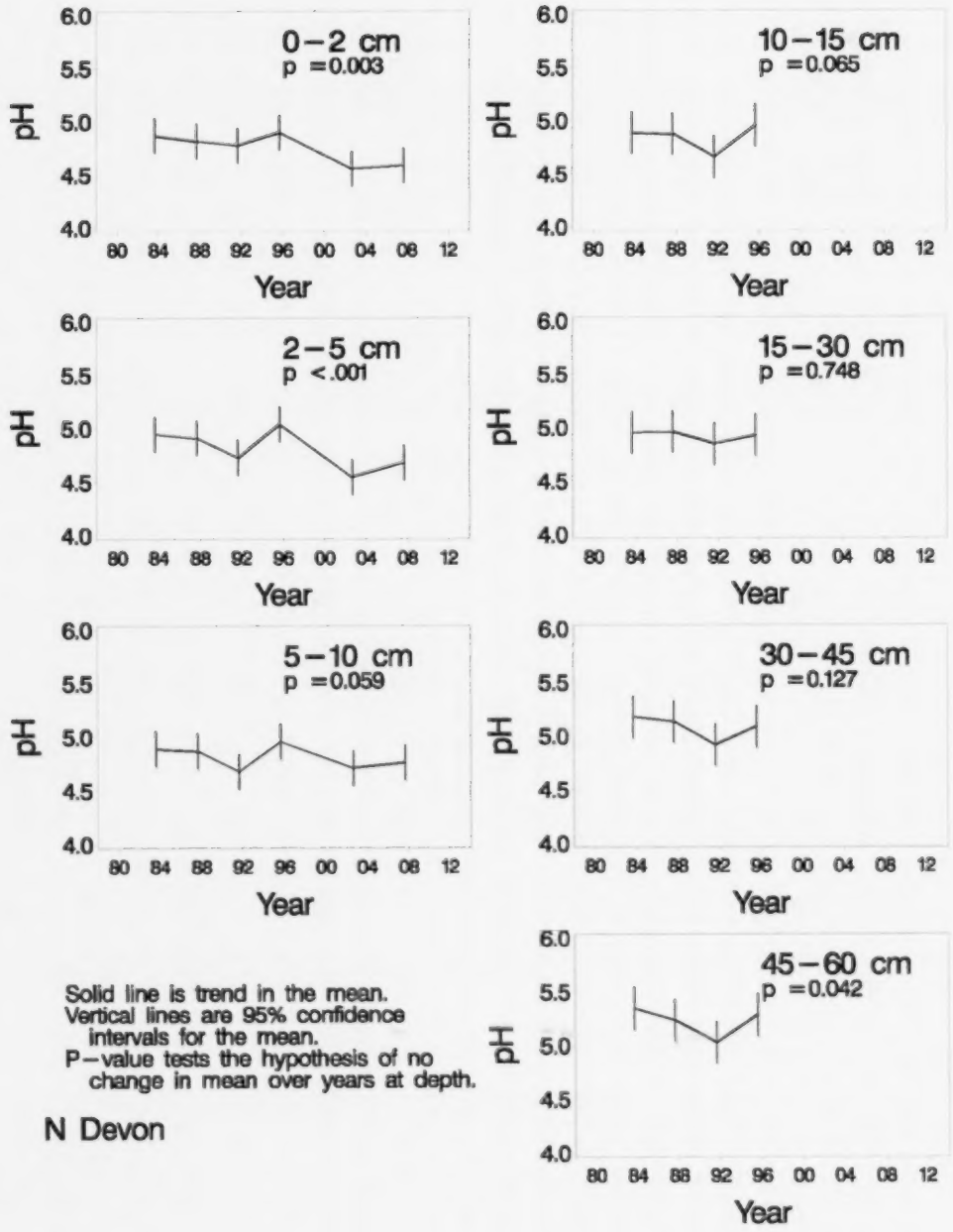
S Fort Saskatchewan



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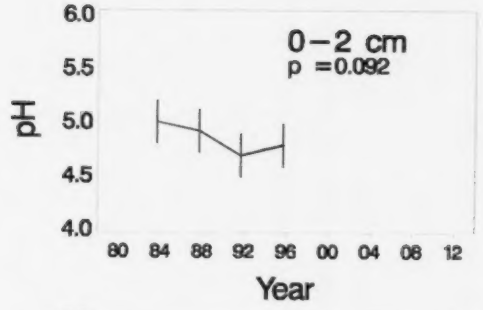
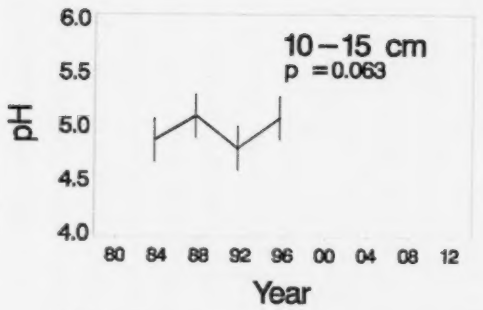
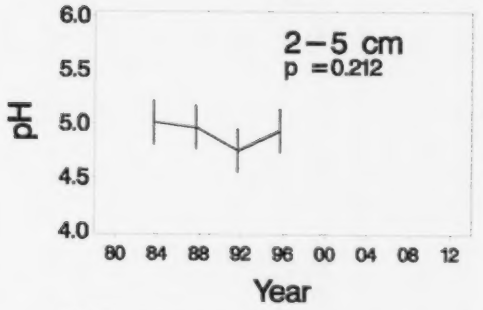
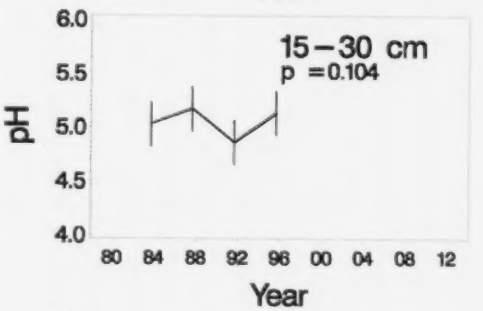
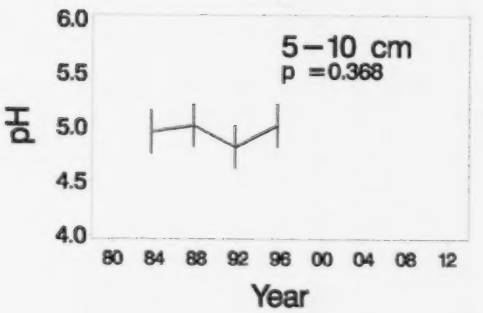
N Devon

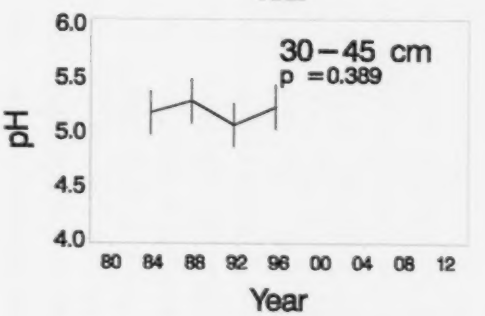












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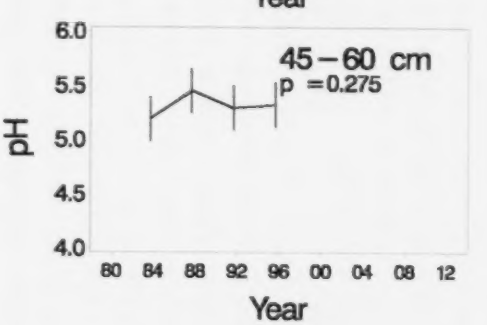

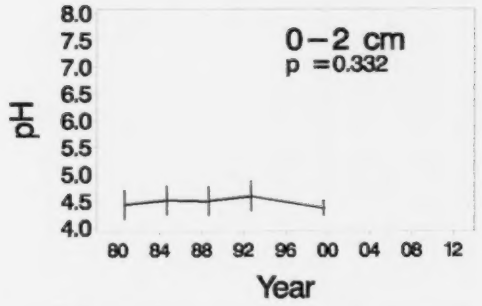

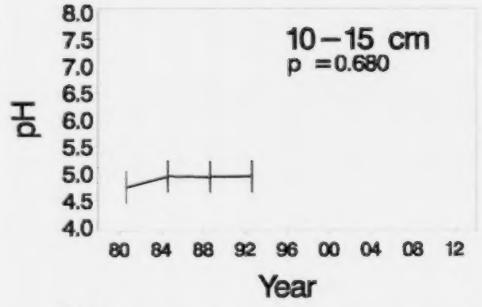

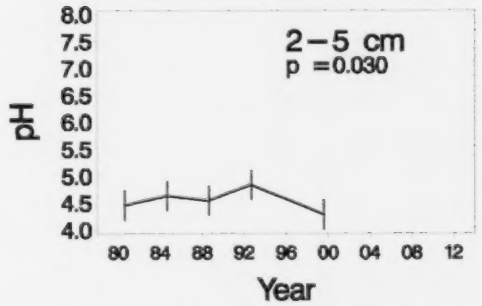

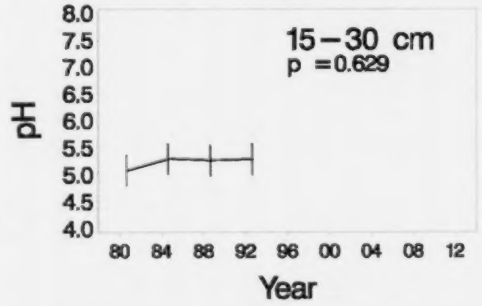

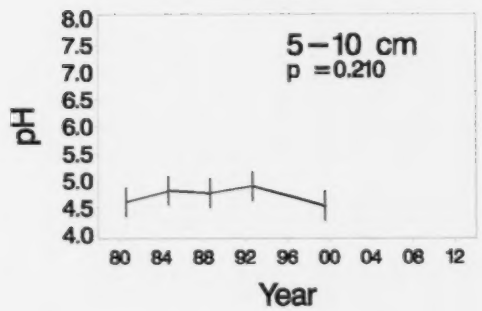

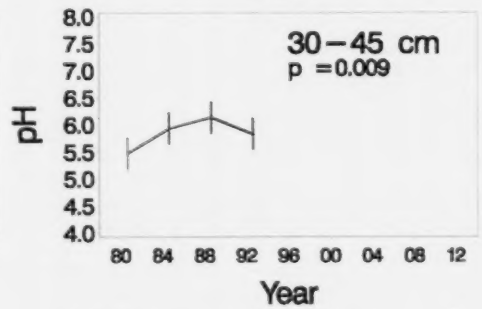

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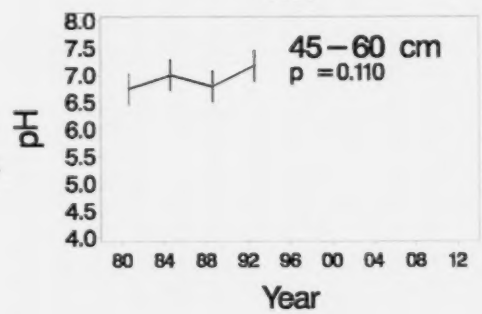
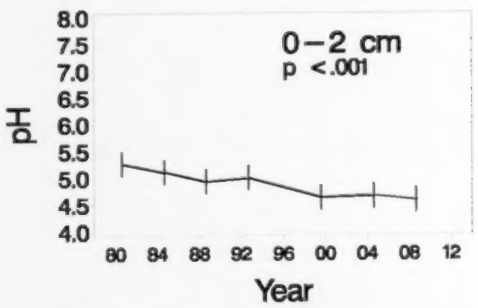
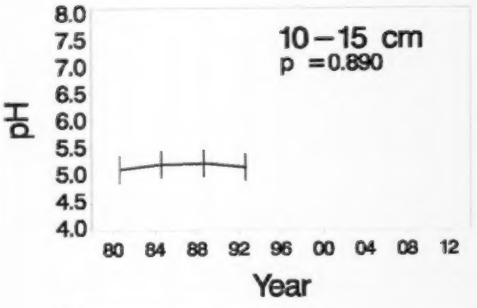
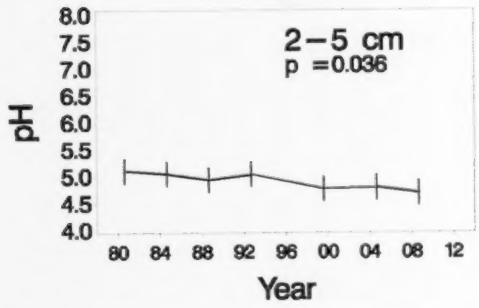
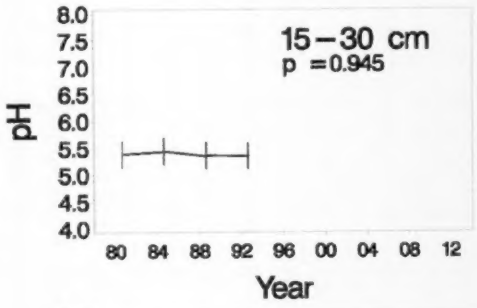
N Rocky Mountain House

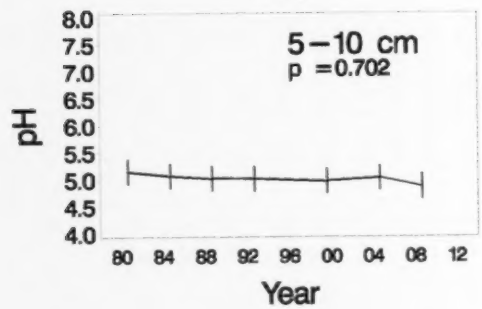


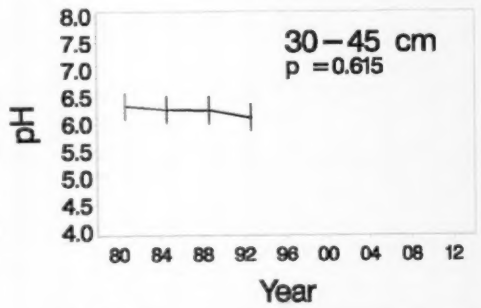












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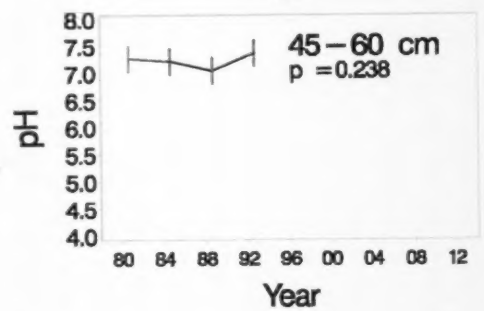
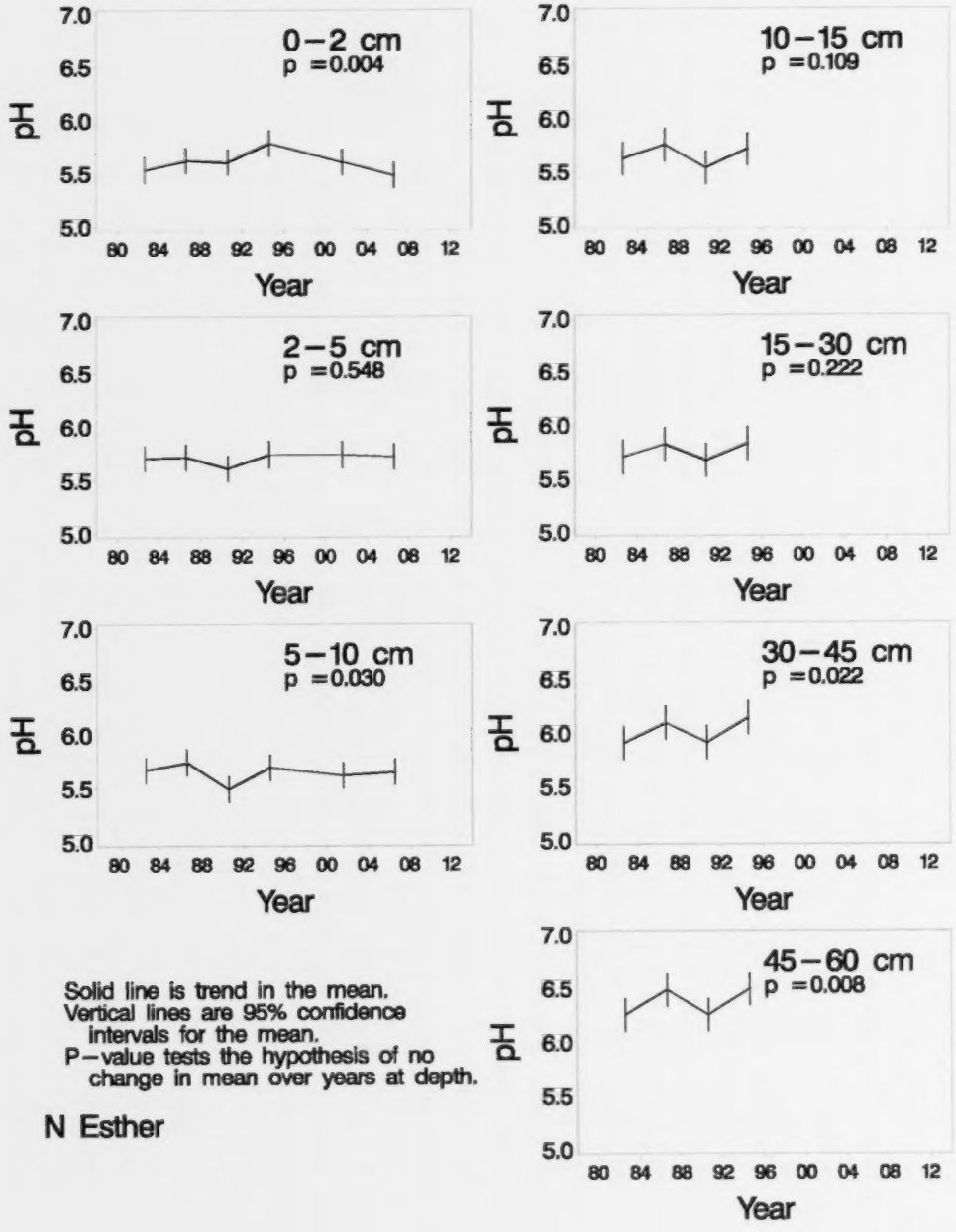
S Rocky Mountain House





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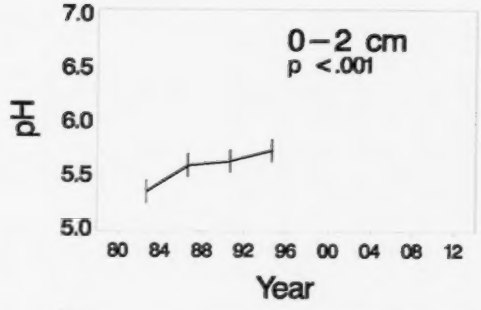
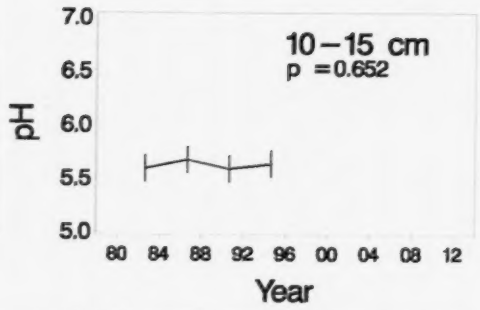
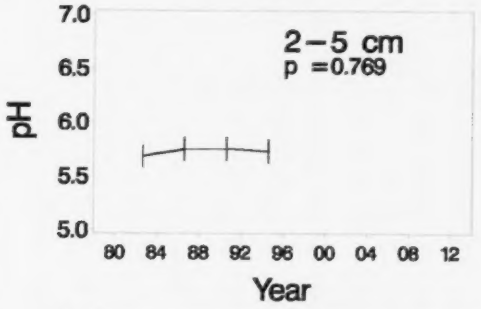
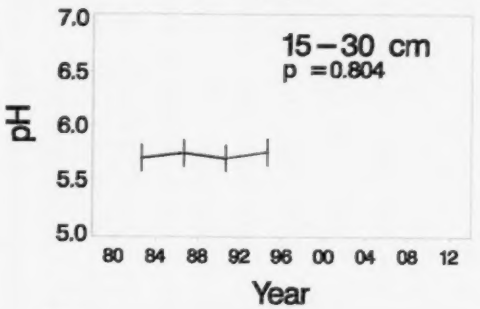
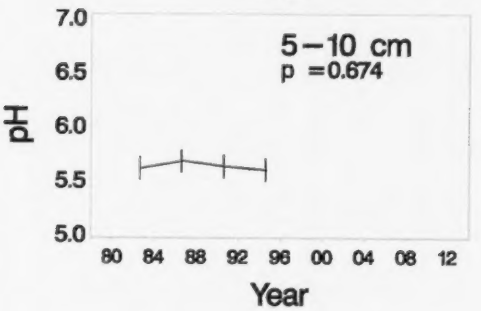
N Esther

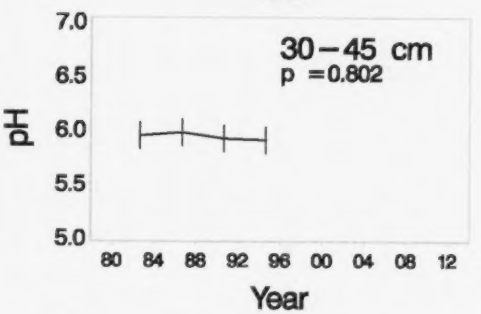












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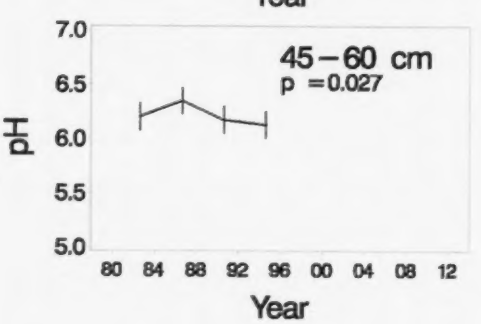
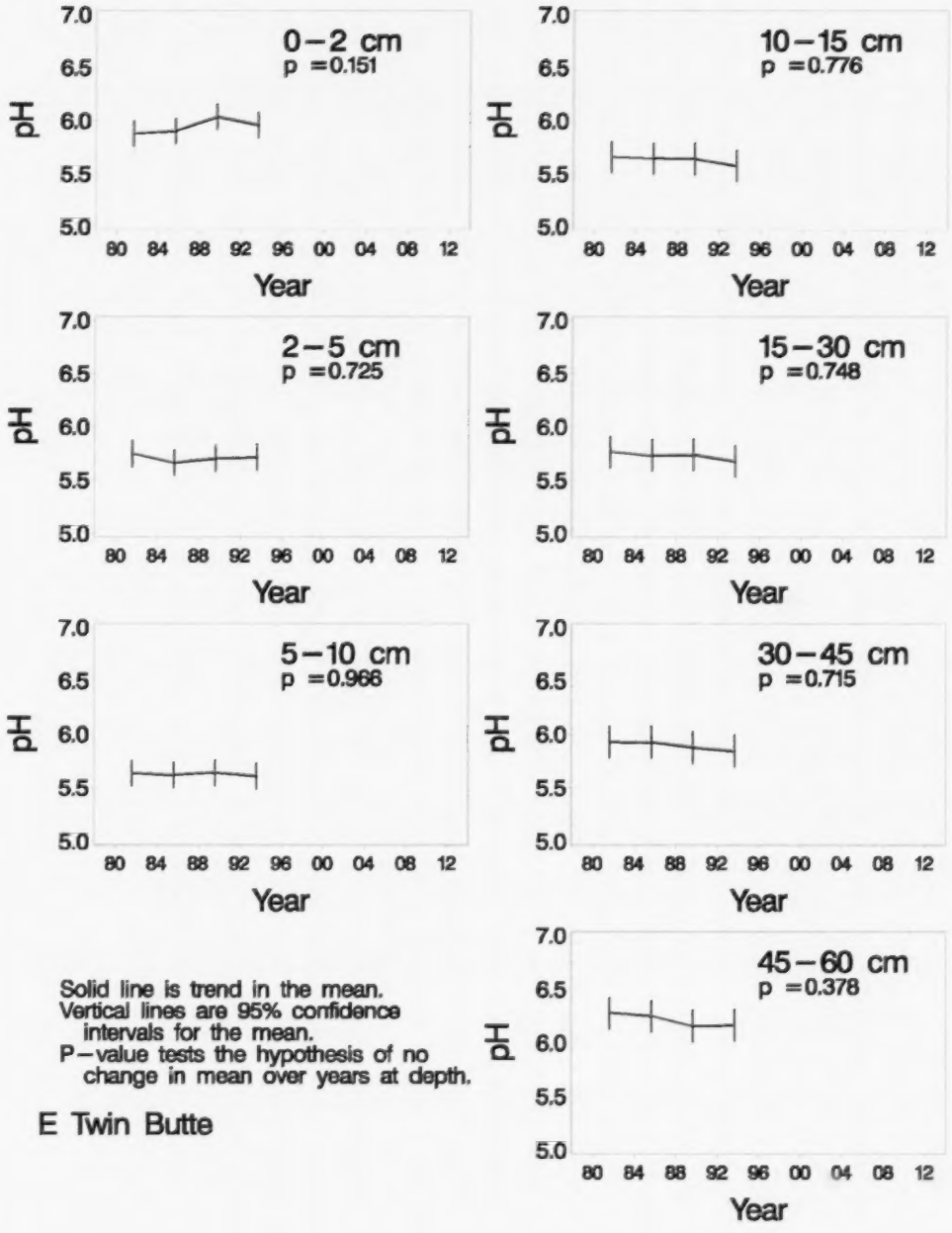
P–value tests the hypothesis of no change in mean over years at depth.

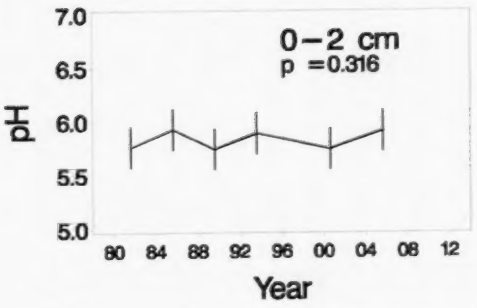
S Esther

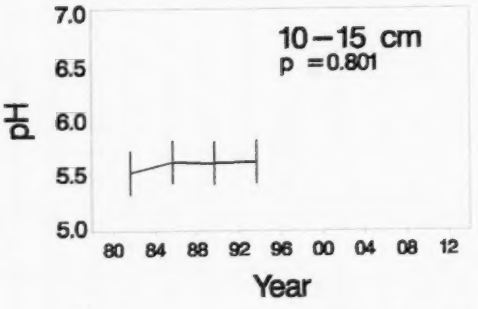


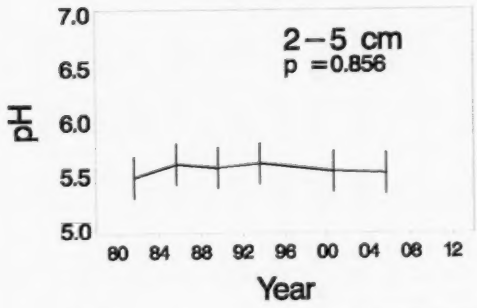


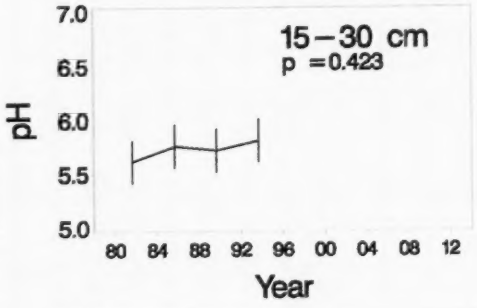
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

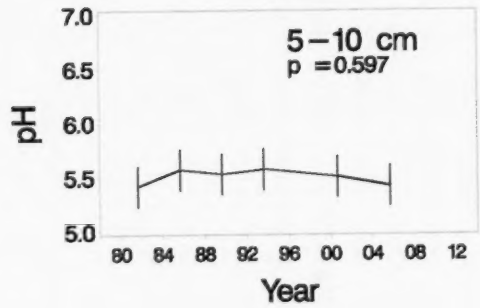
E Twin Butte

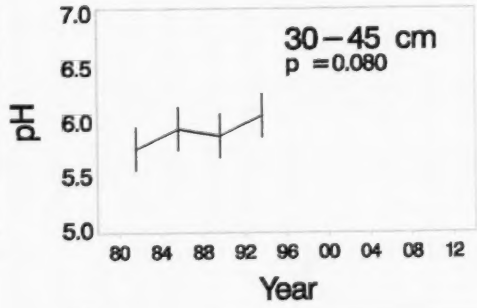




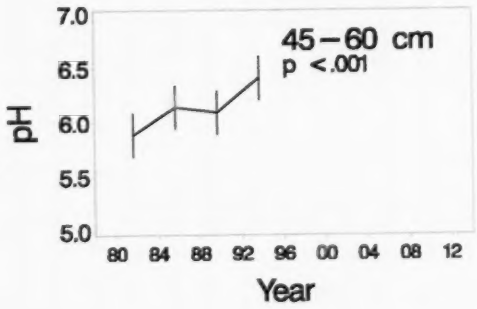








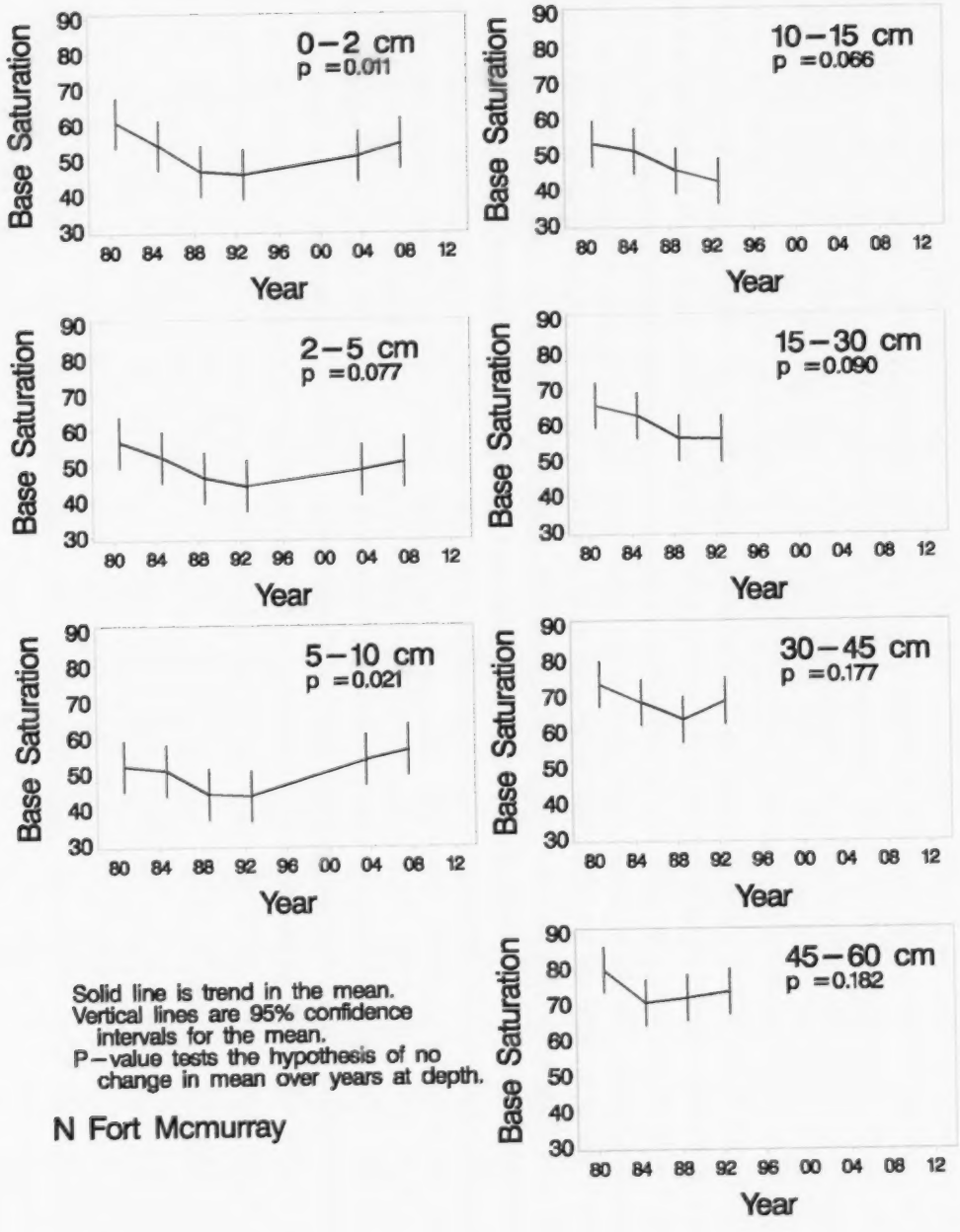
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.



W Twin Butte

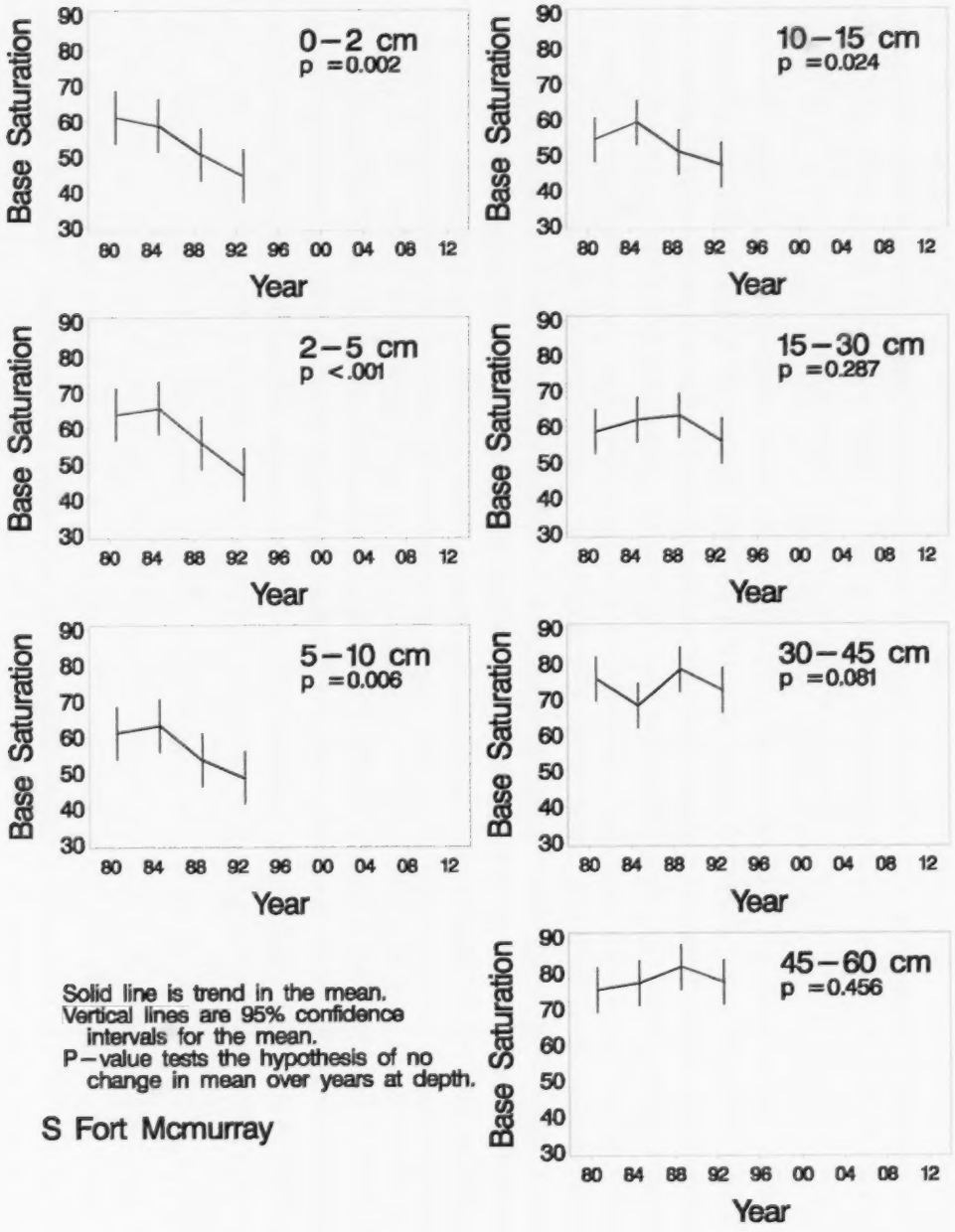
APPENDIX C2

GRAPHICAL PRESENTATION OF SATURATION PERCENTAGE OF EXCHANGEABLE BASE CATIONS AT ALL SITES



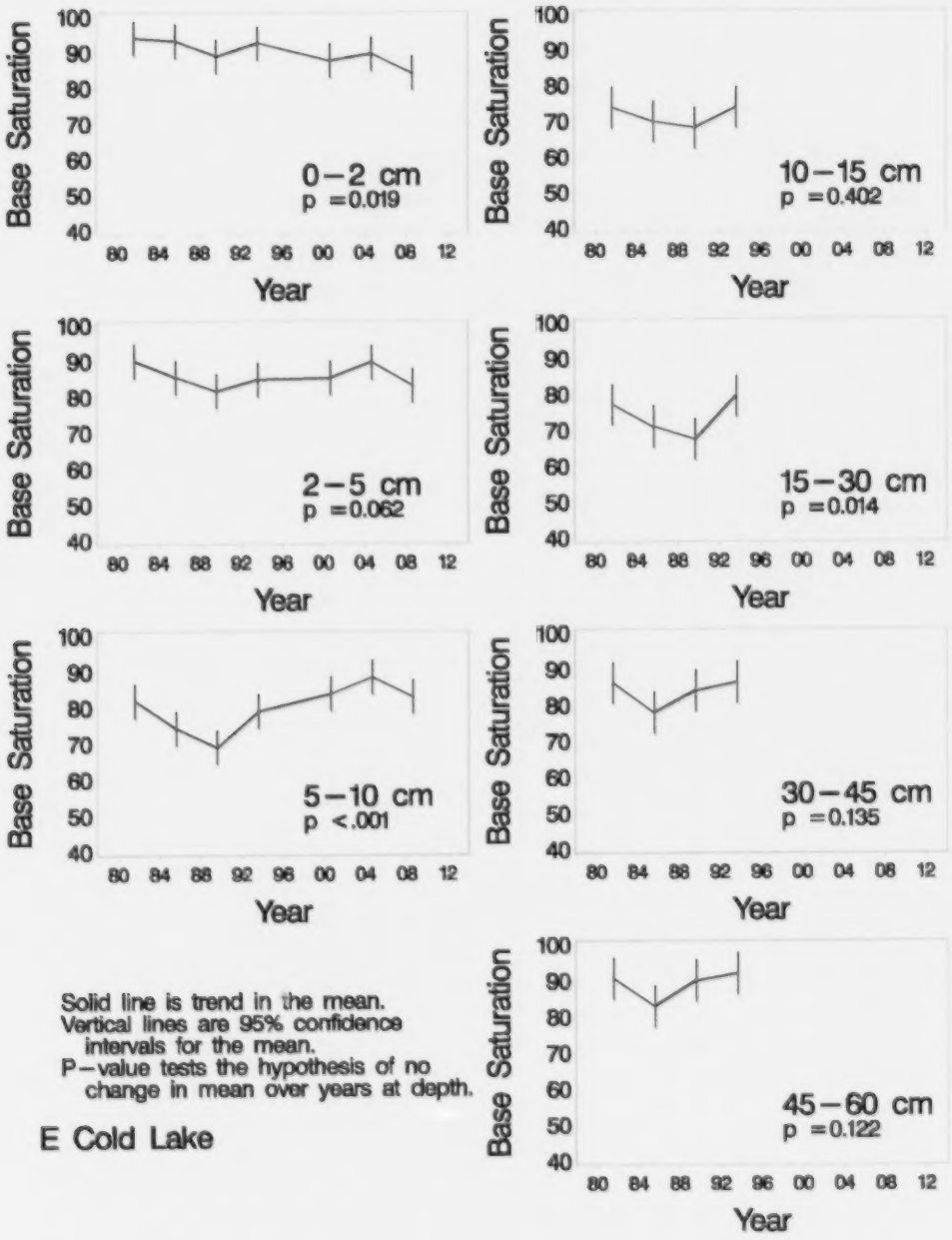
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

N Fort Mcmurray



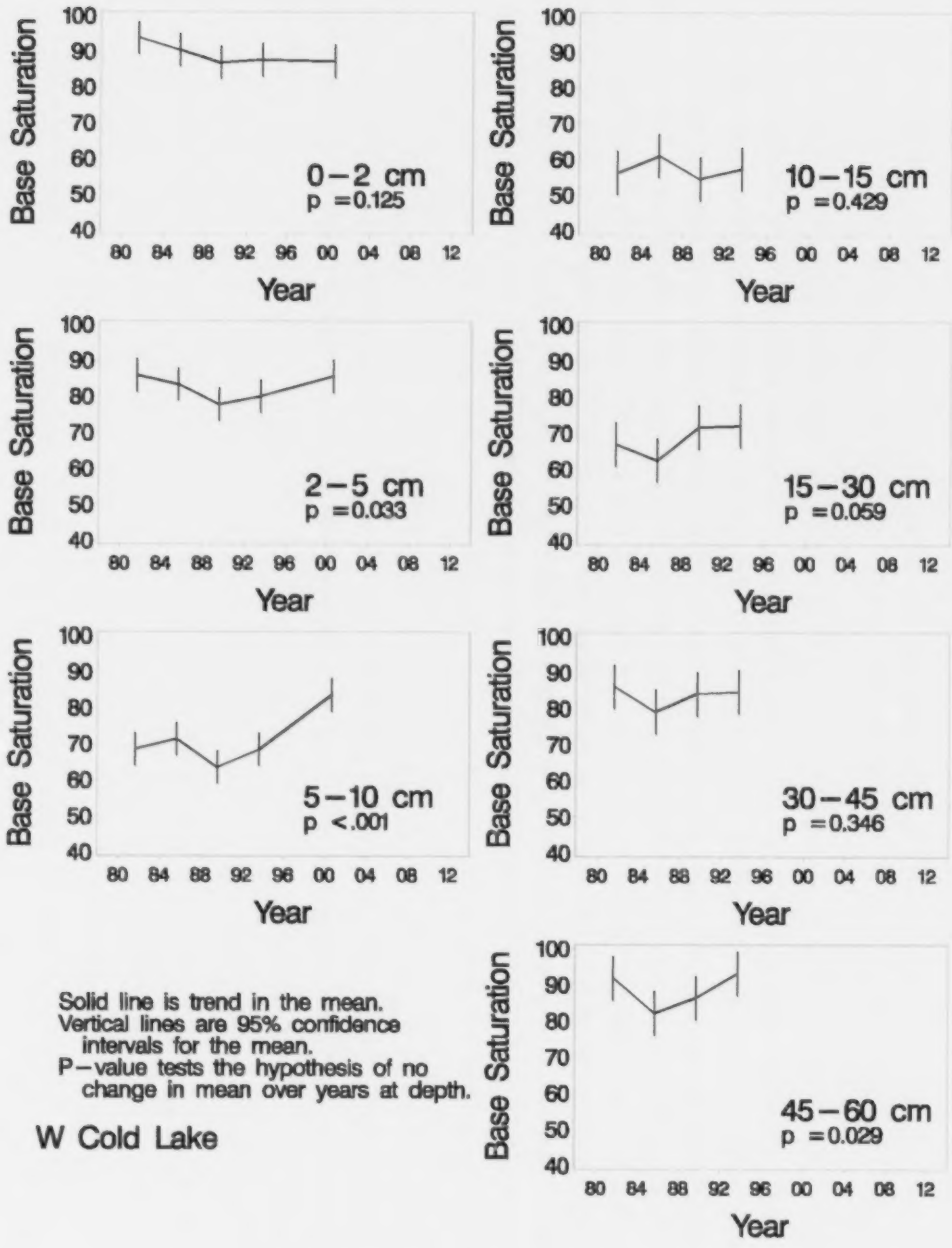
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

S Fort Mcmurray



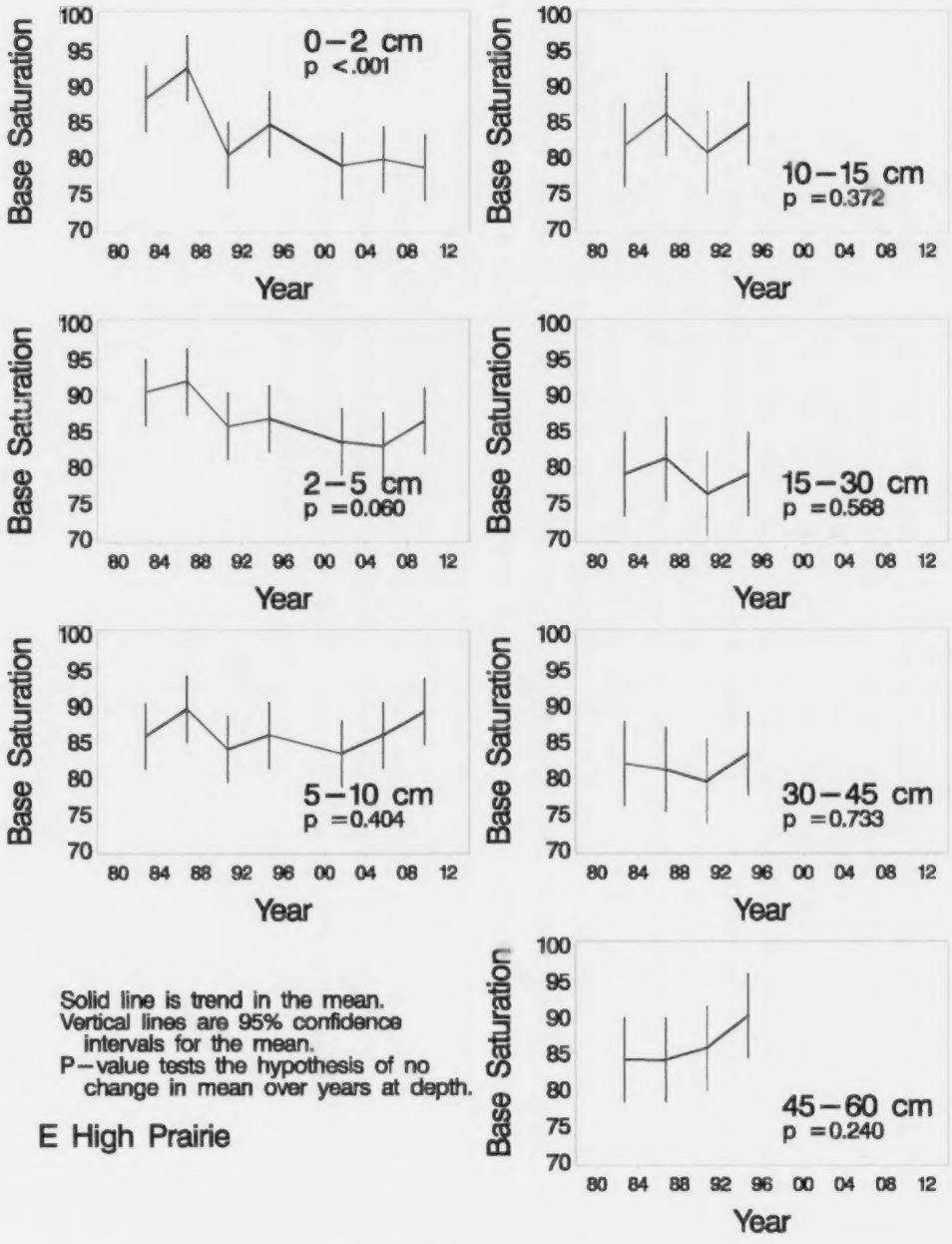
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

E Cold Lake



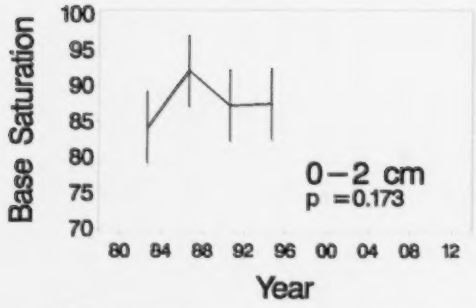
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P−value tests the hypothesis of no change in mean over years at depth.

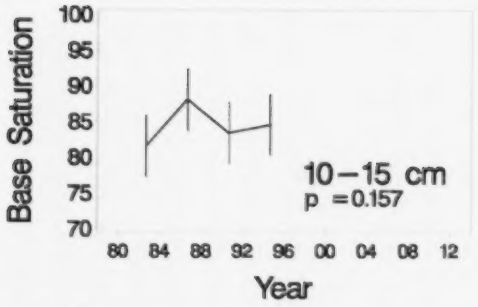
W Cold Lake

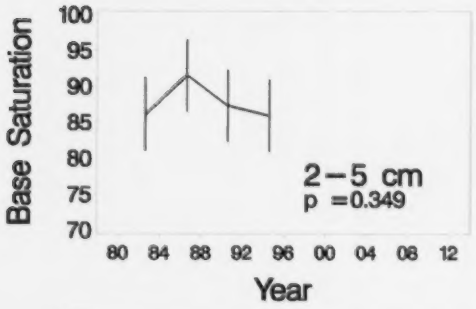


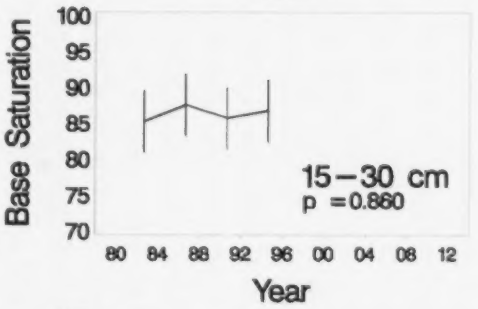
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

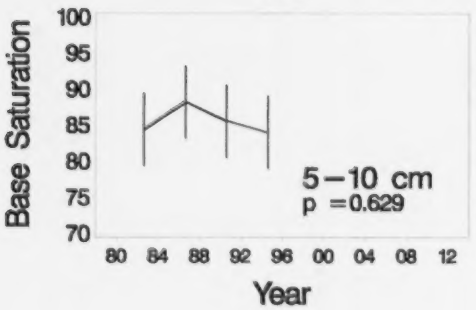
E High Prairie

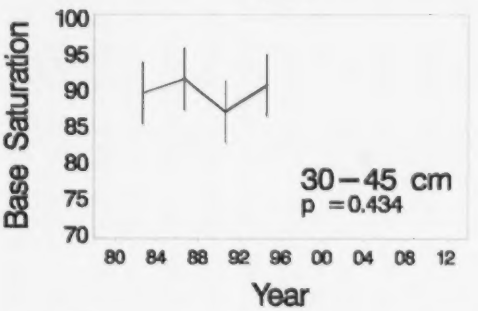






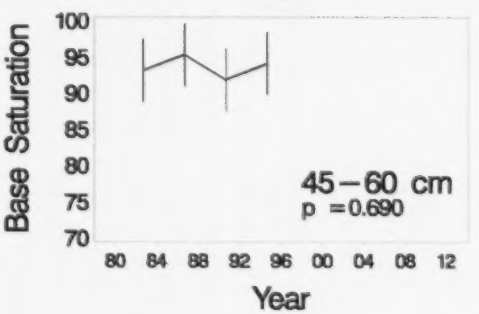


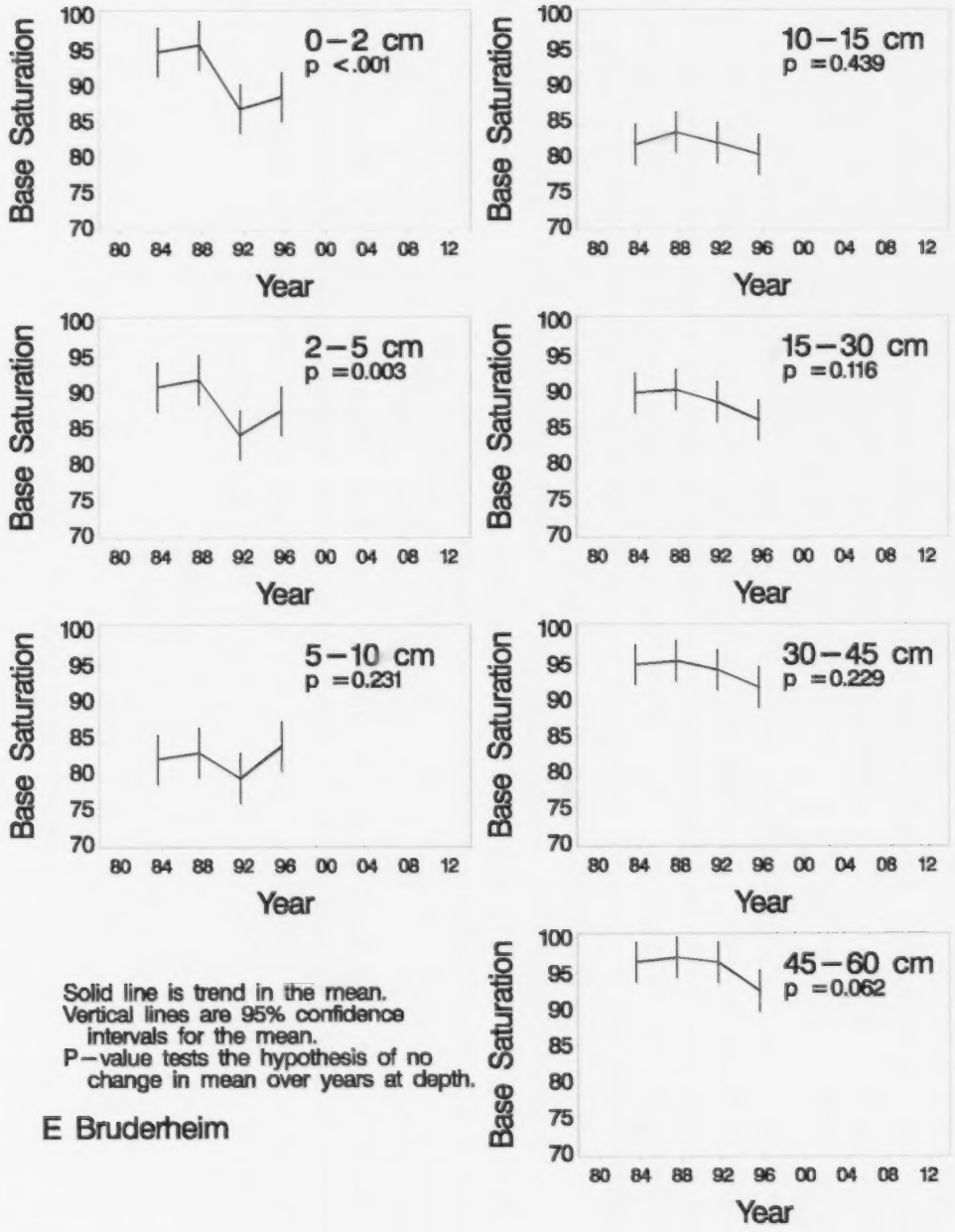




Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

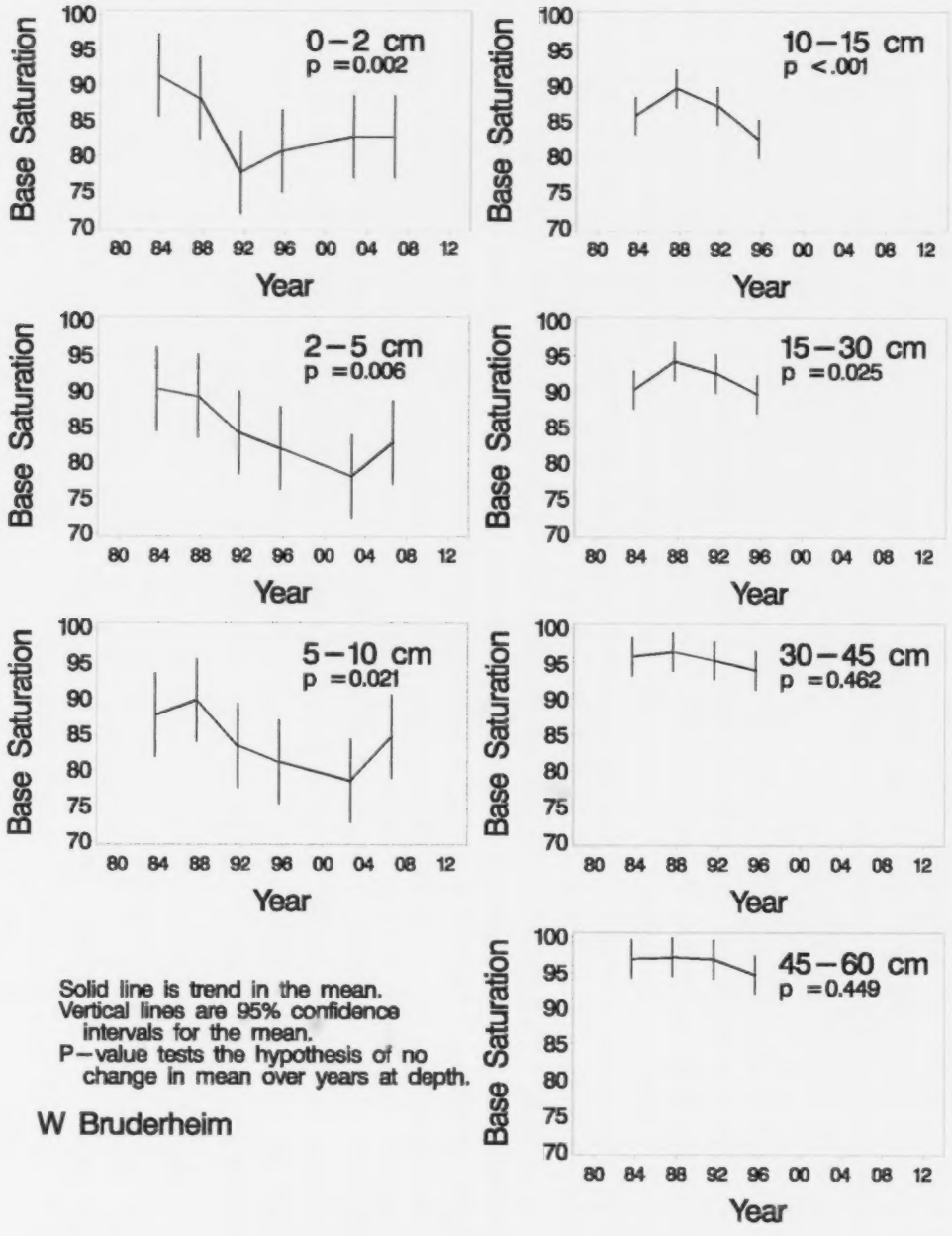
W High Prairie





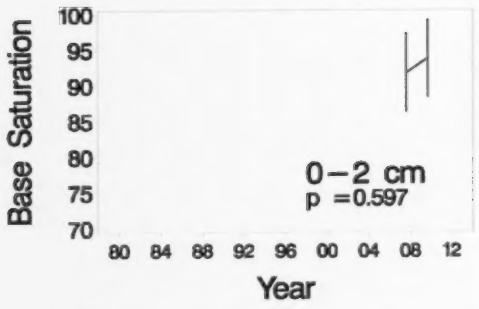
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

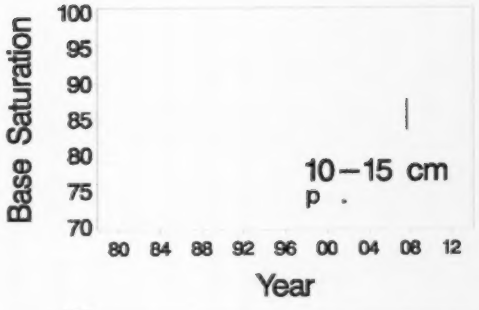
E Bruderheim

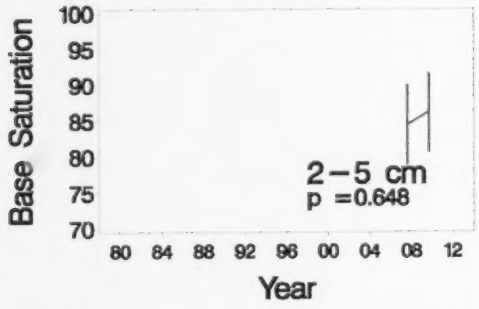


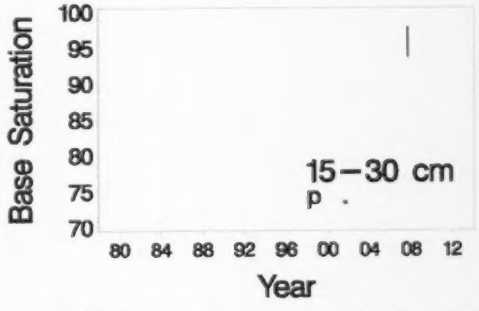
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

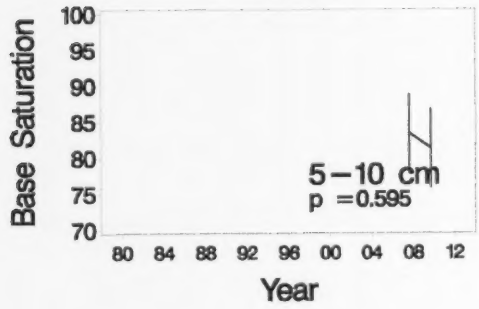
W Bruderheim

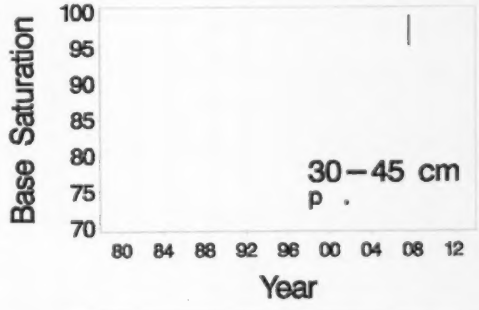


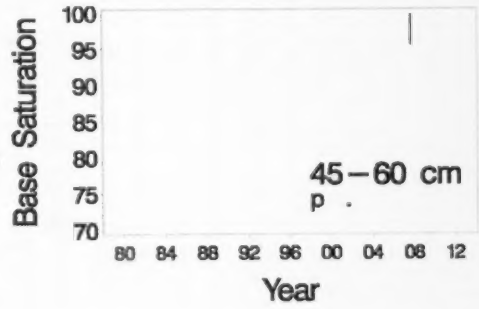






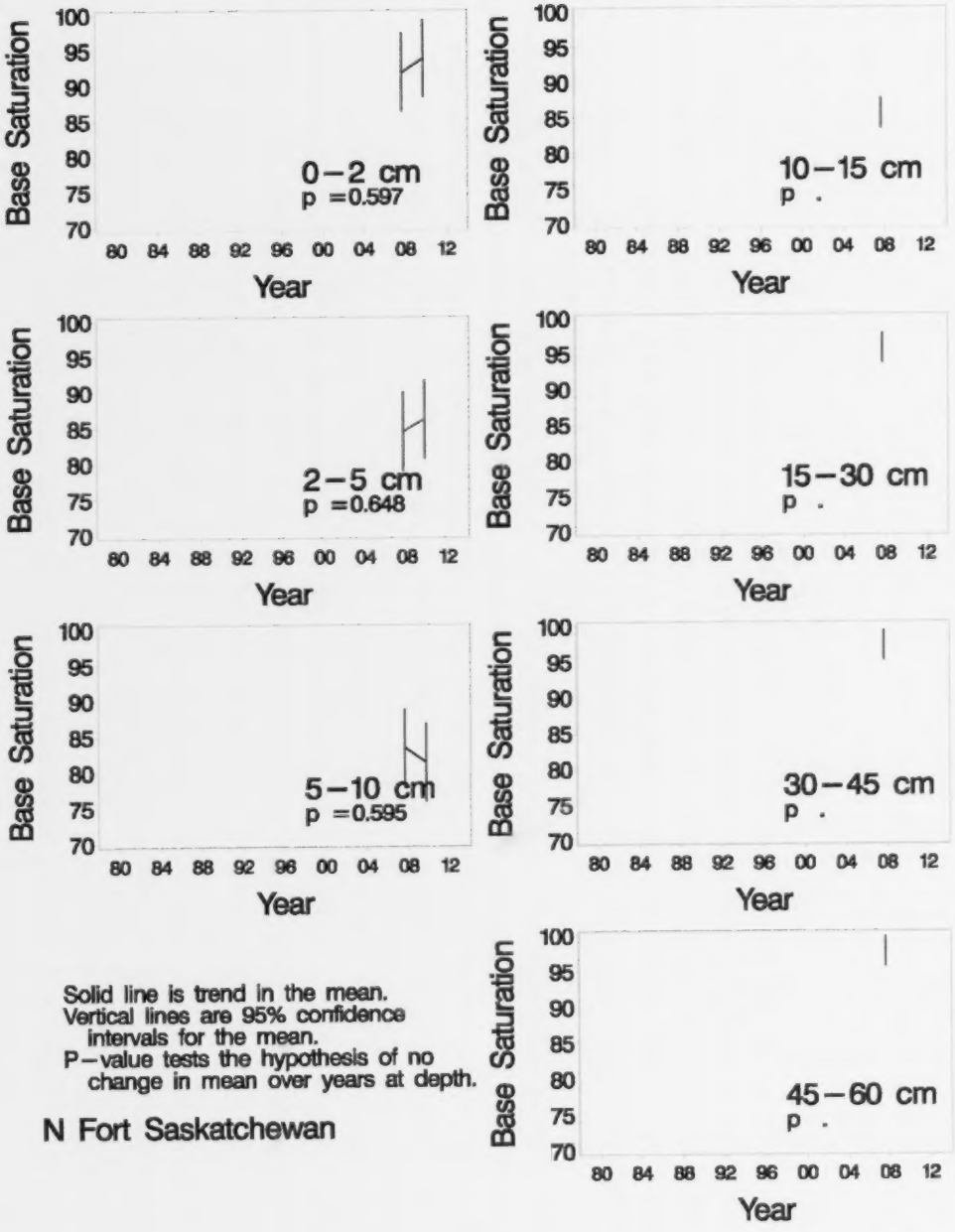






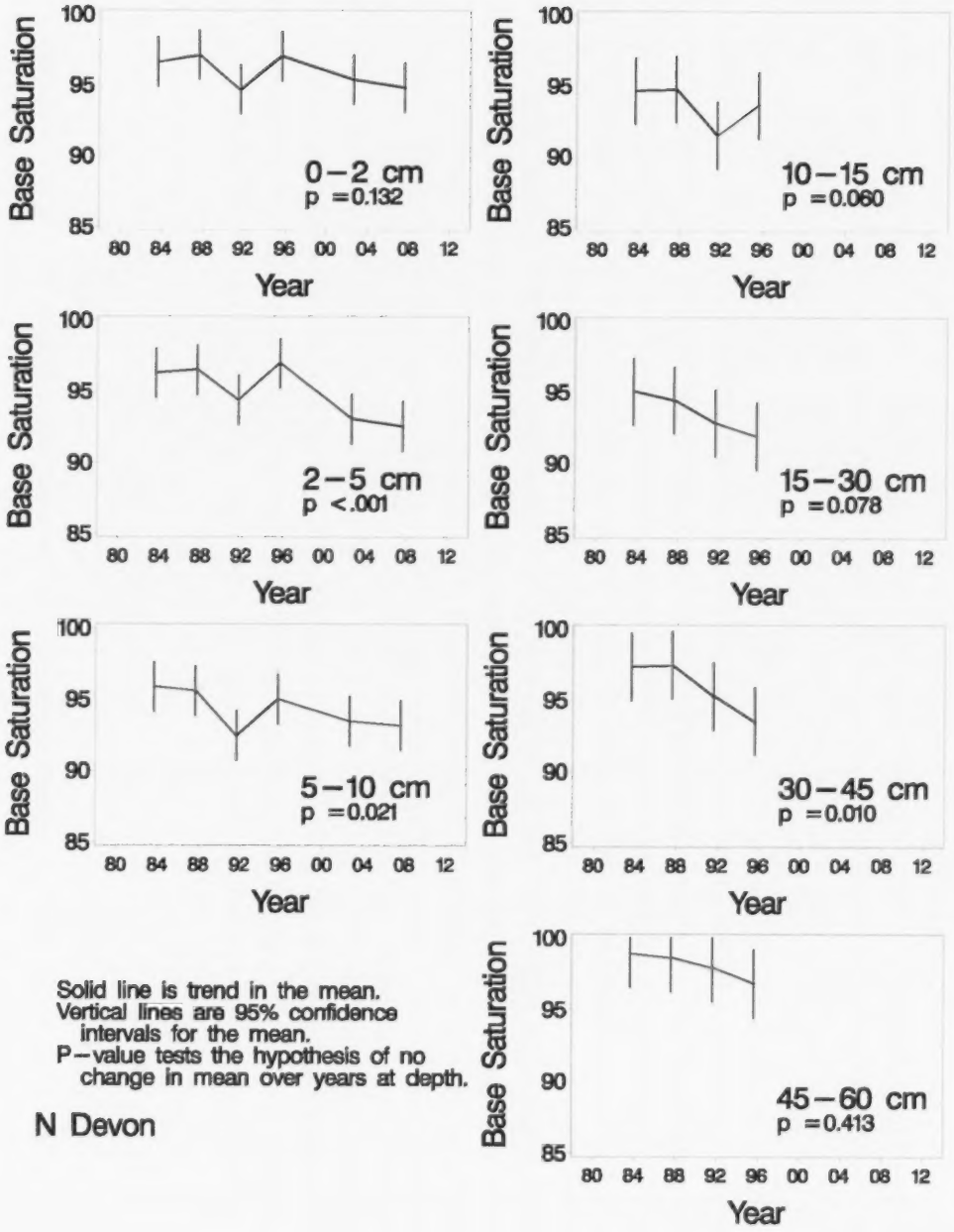
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

N Fort Saskatchewan



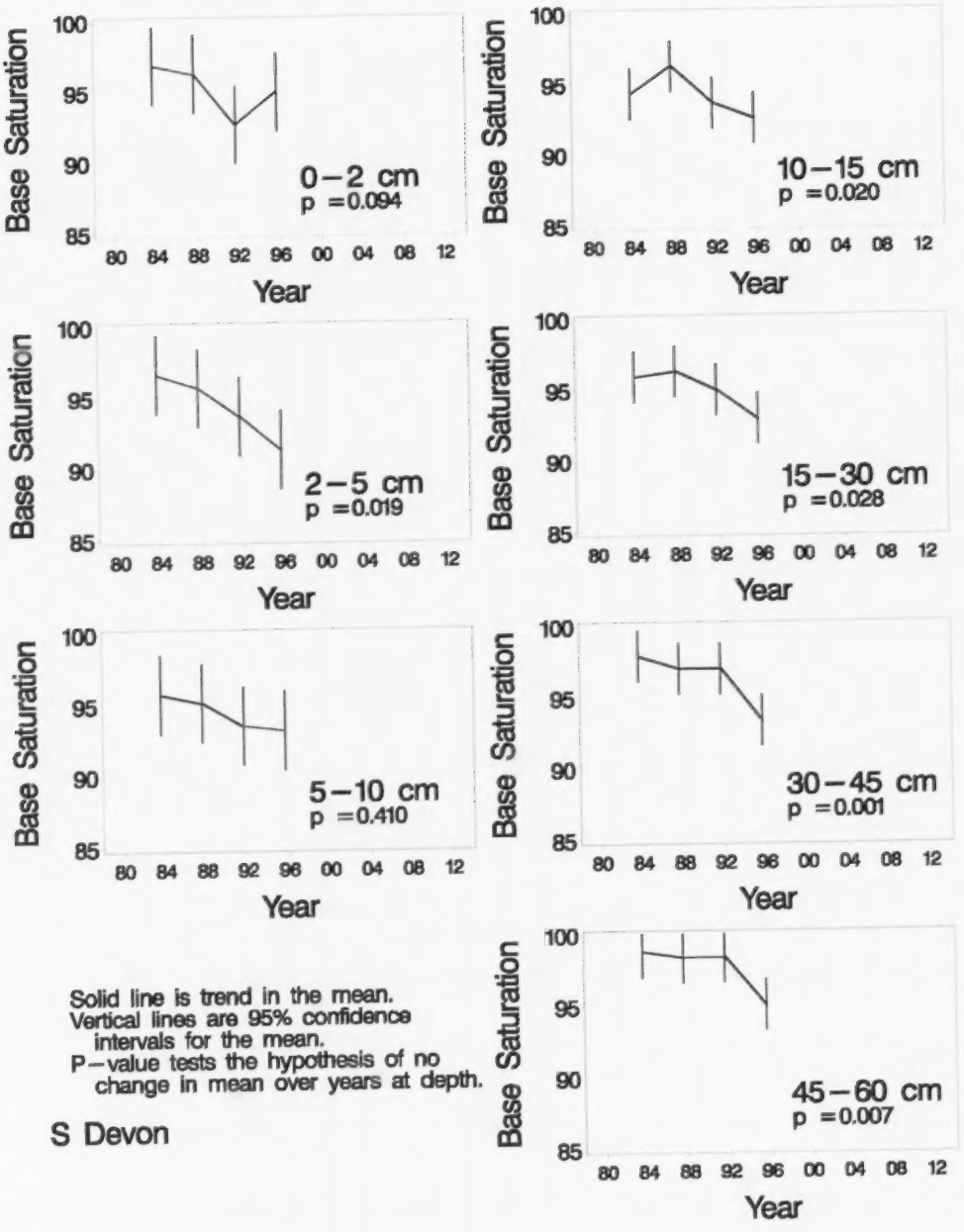
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

N Fort Saskatchewan



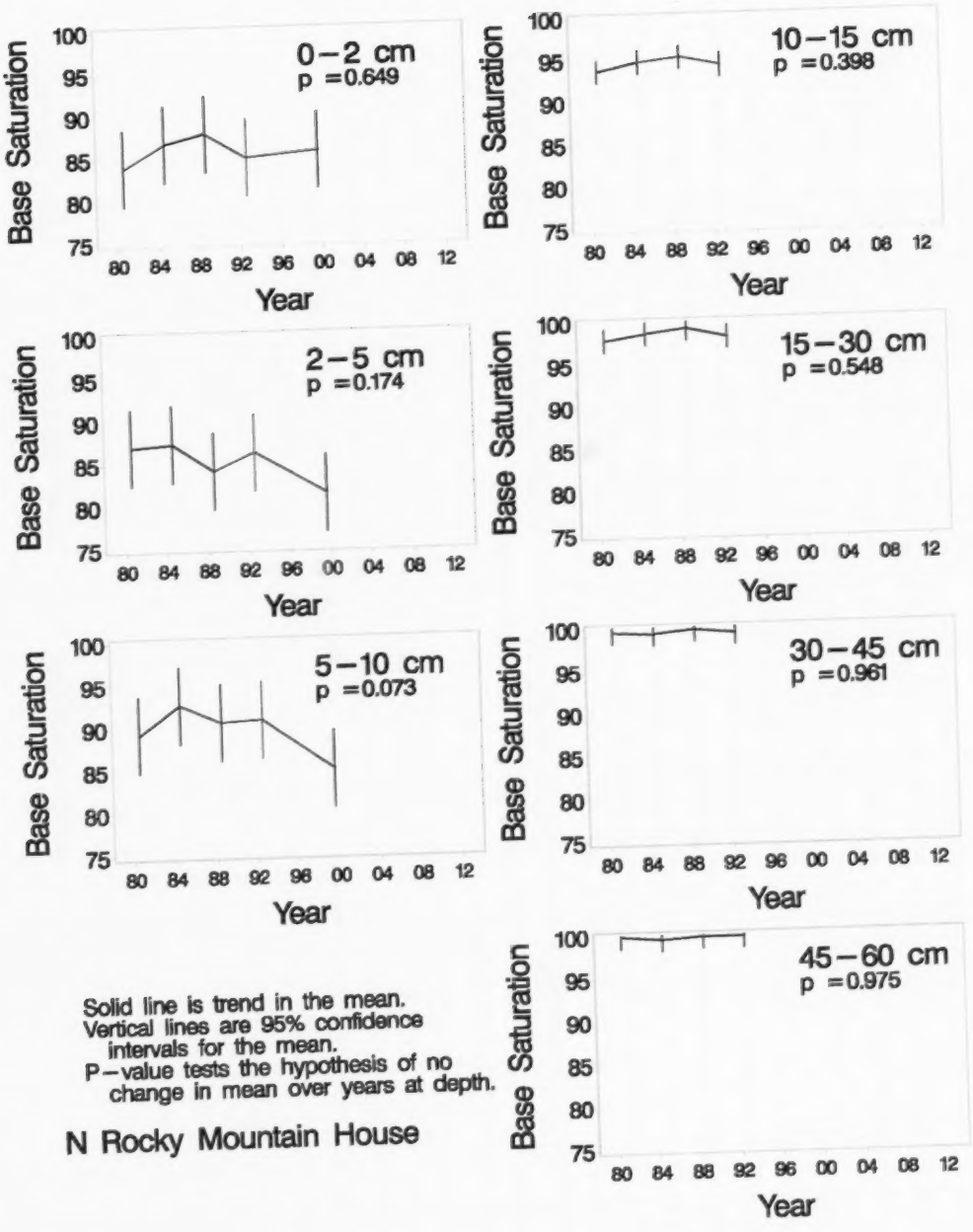
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

N Devon



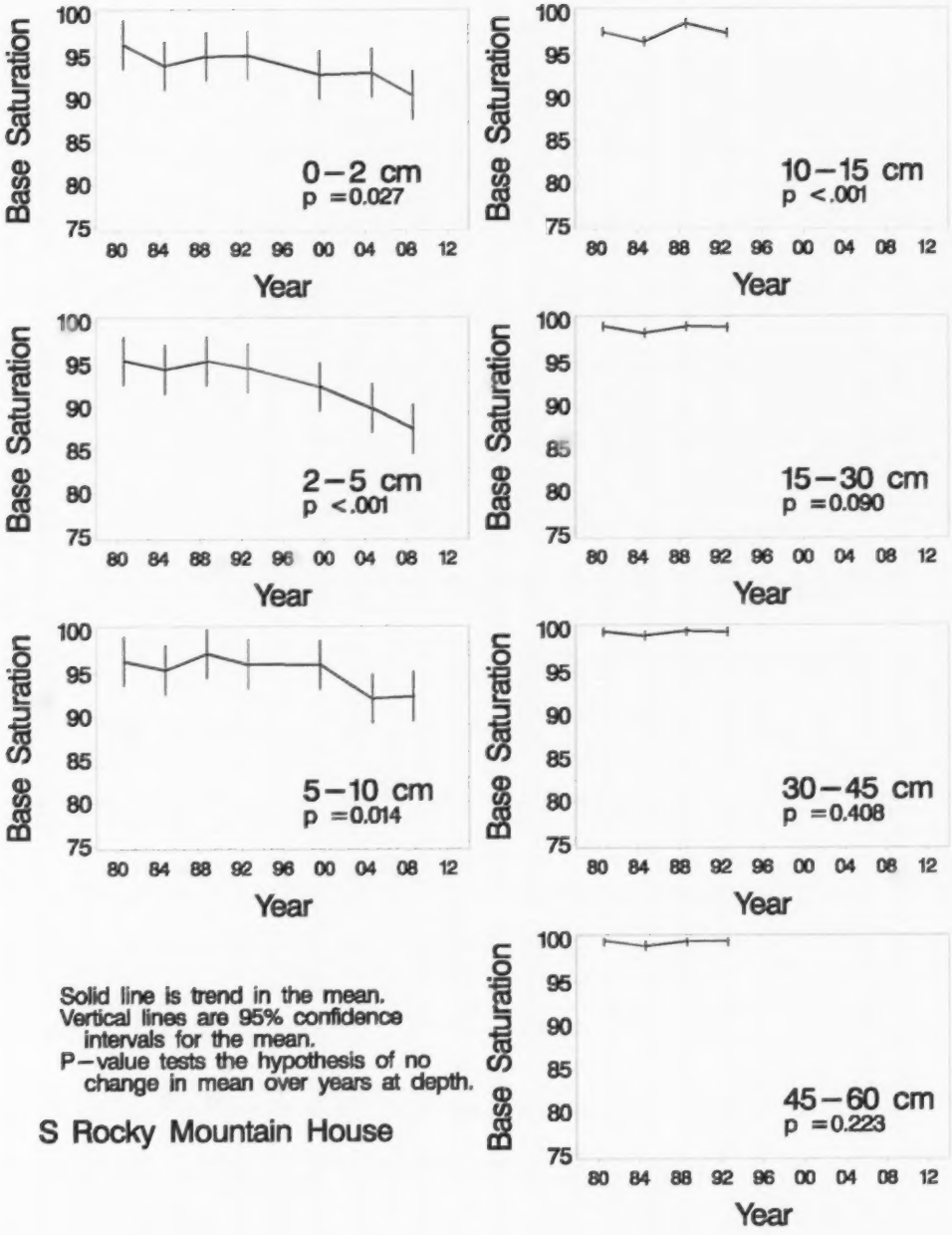
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

S Devon



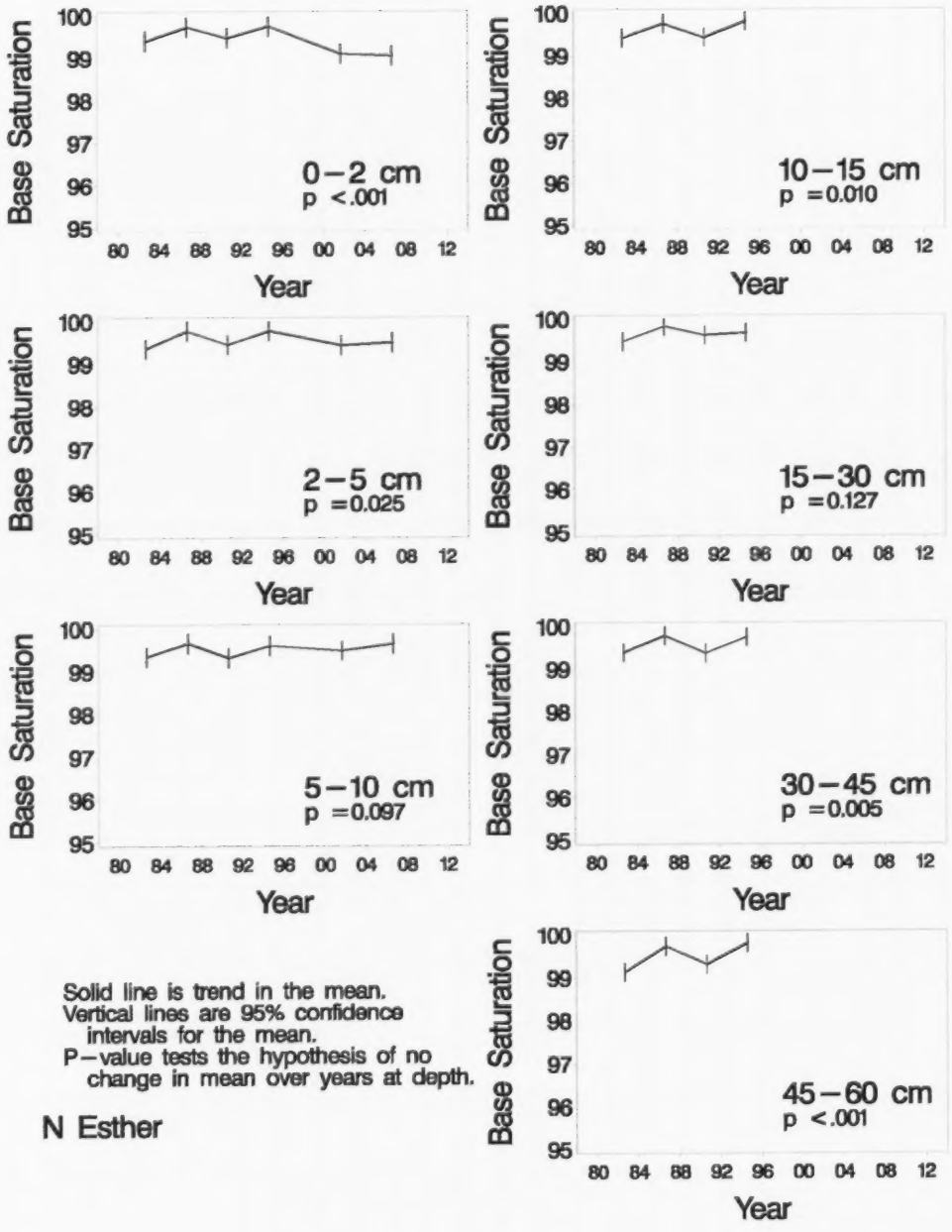
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

N Rocky Mountain House



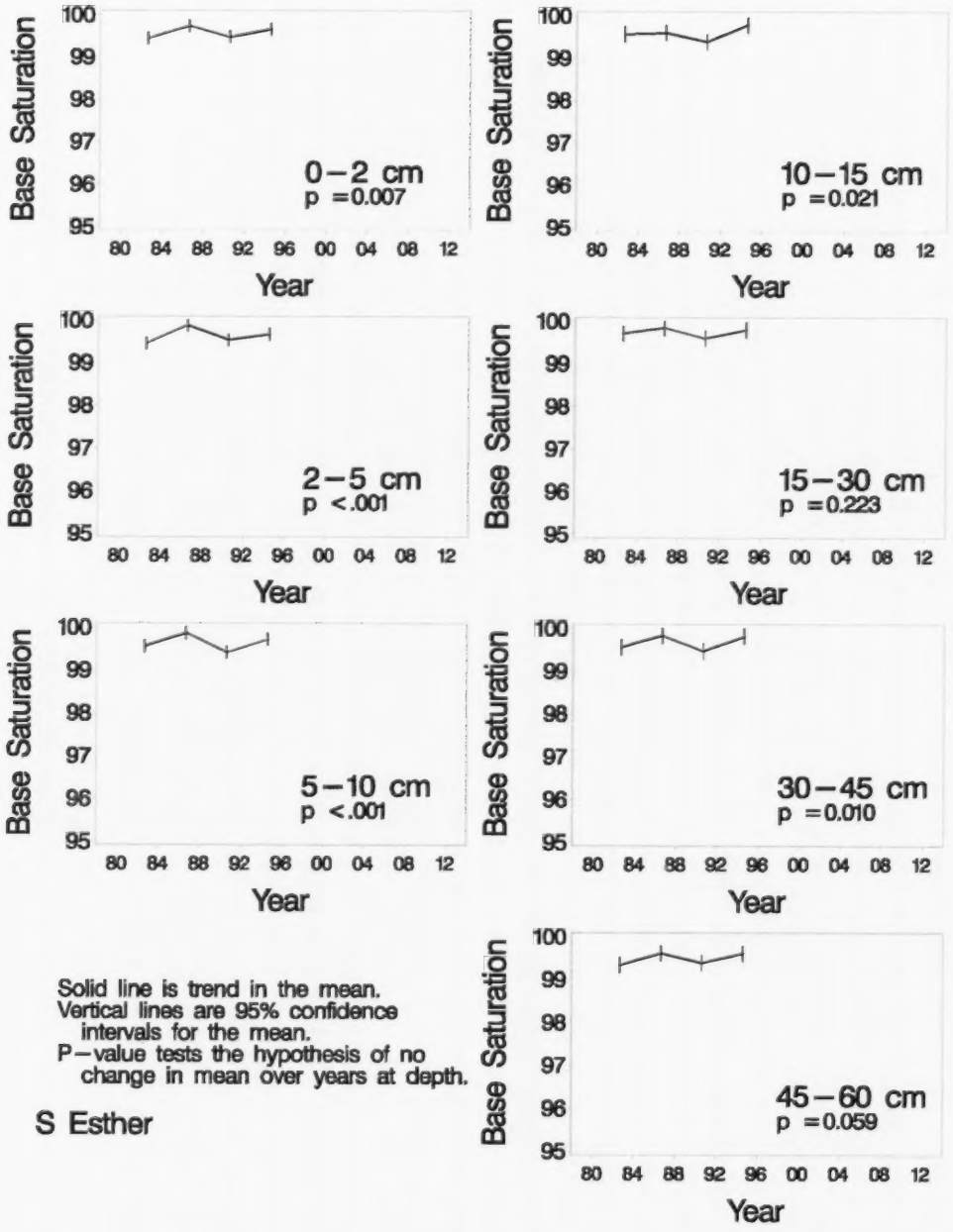
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

S Rocky Mountain House



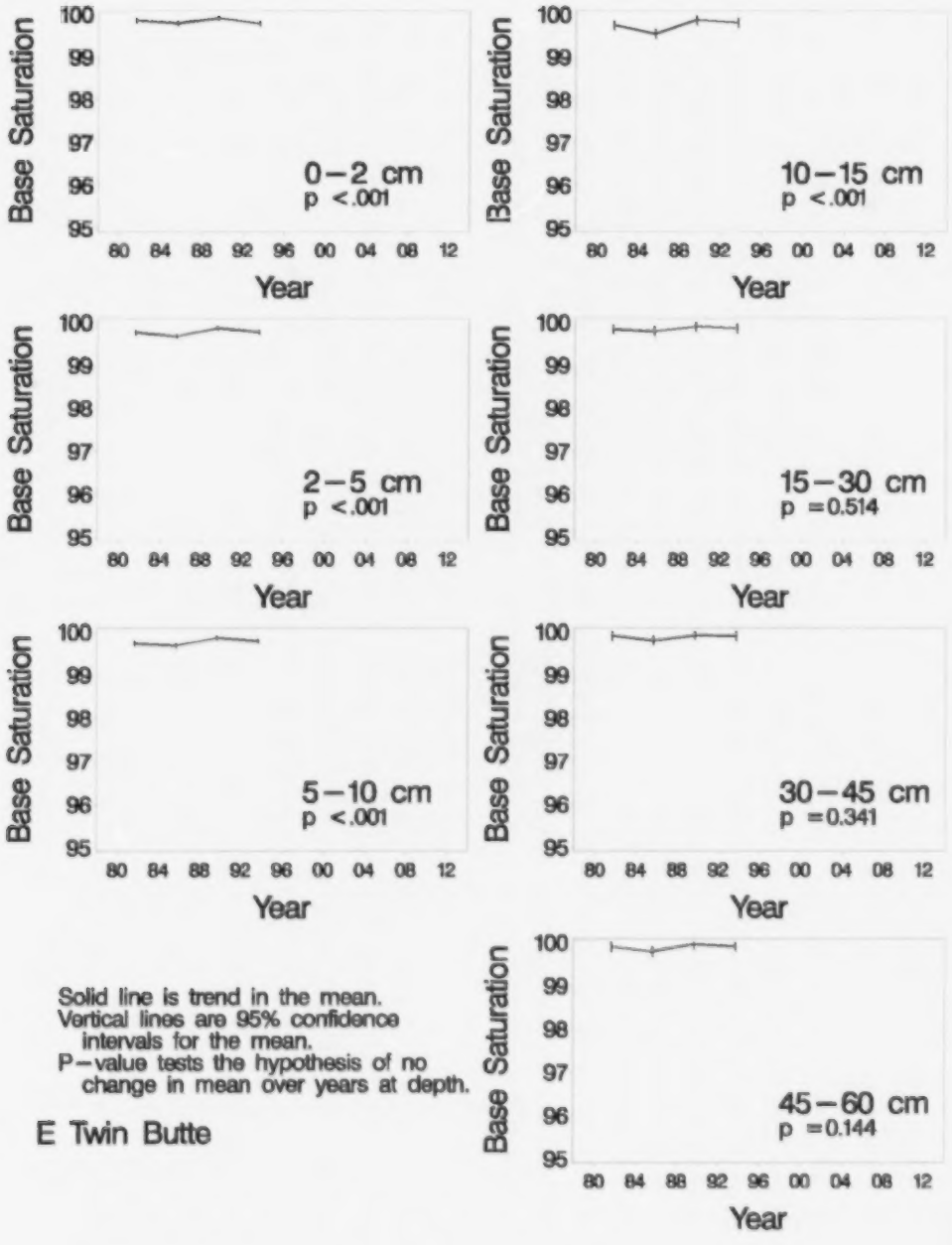
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P−value tests the hypothesis of no change in mean over years at depth.

N Esther



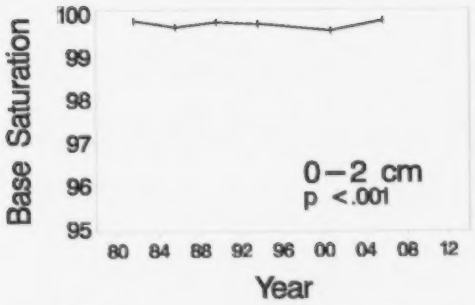
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P−value tests the hypothesis of no change in mean over years at depth.

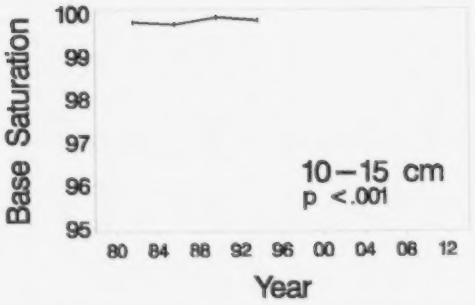
S Esther

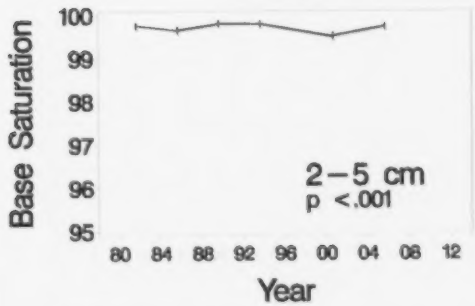


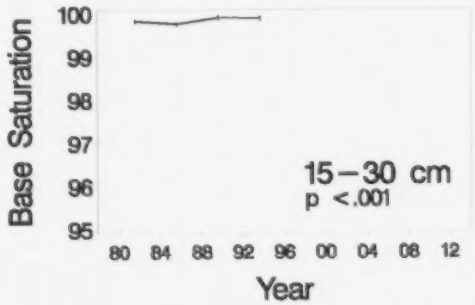
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

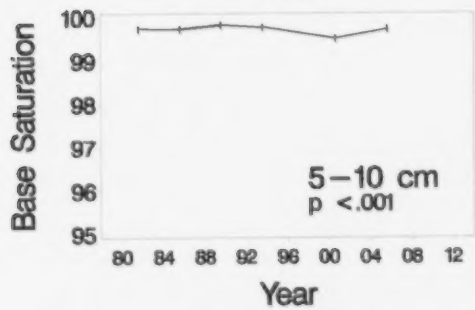
E Twin Butte

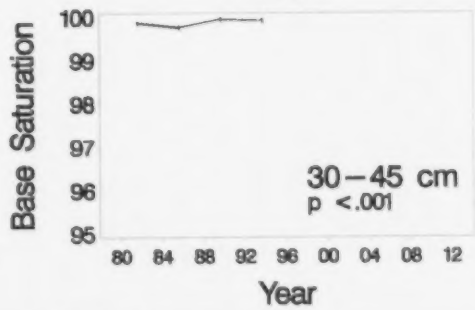


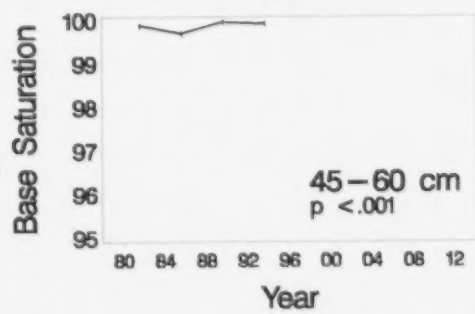










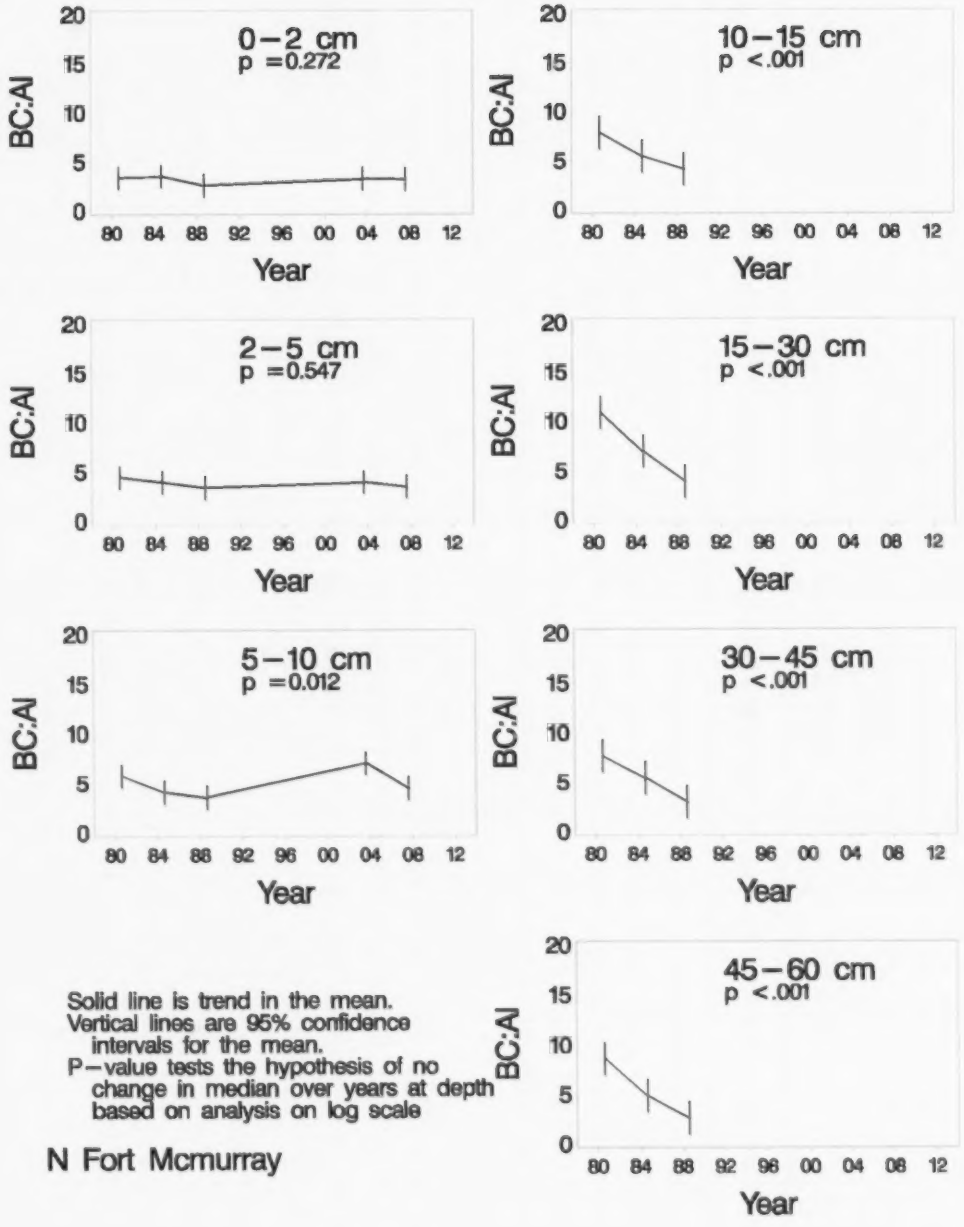


Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in mean over years at depth.

W Twin Butte

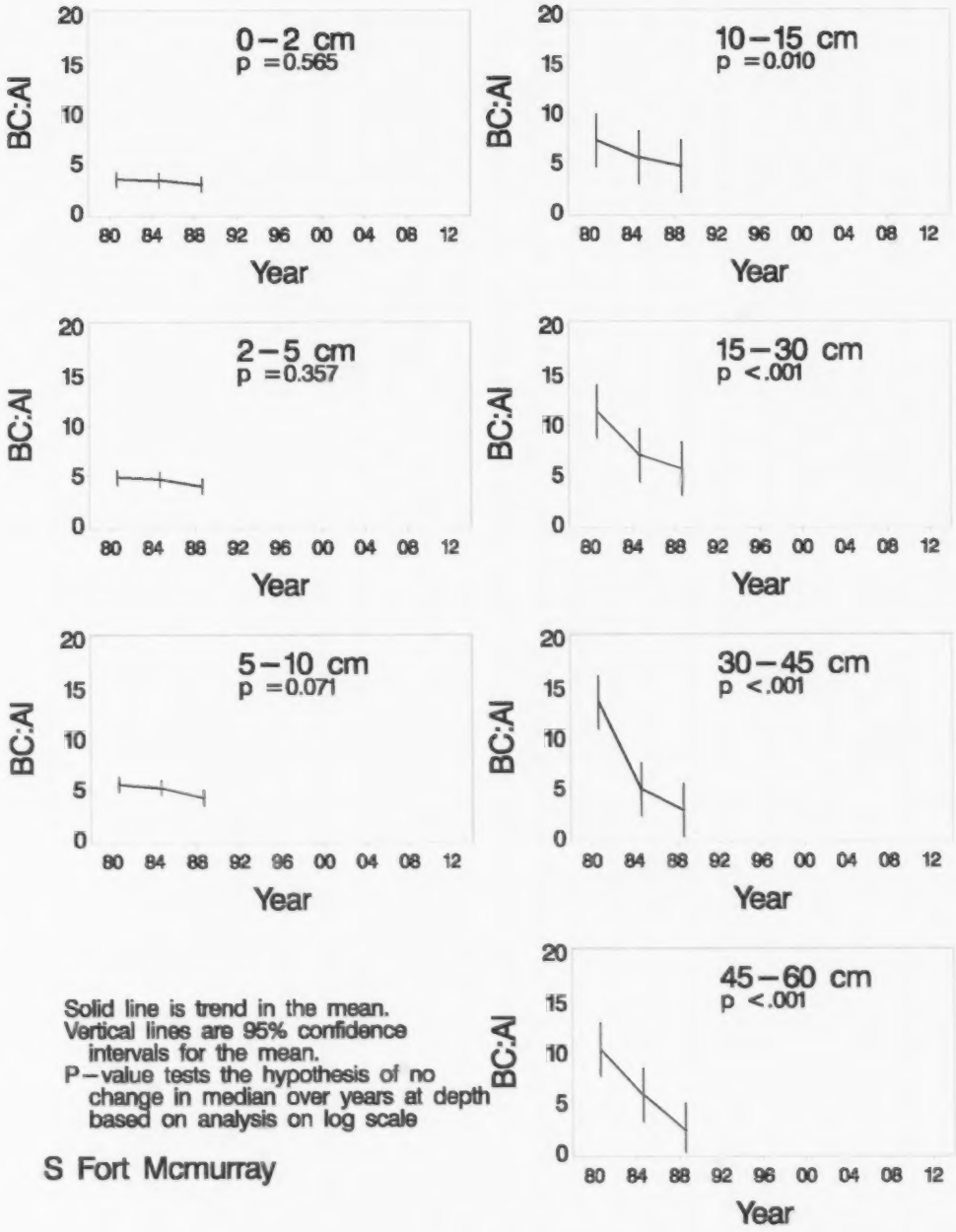
APPENDIX C3

GRAPHICAL PRESENTATION OF CALCIUM:ALUMINUM (BC:AL) RATIO AT ALL SITES



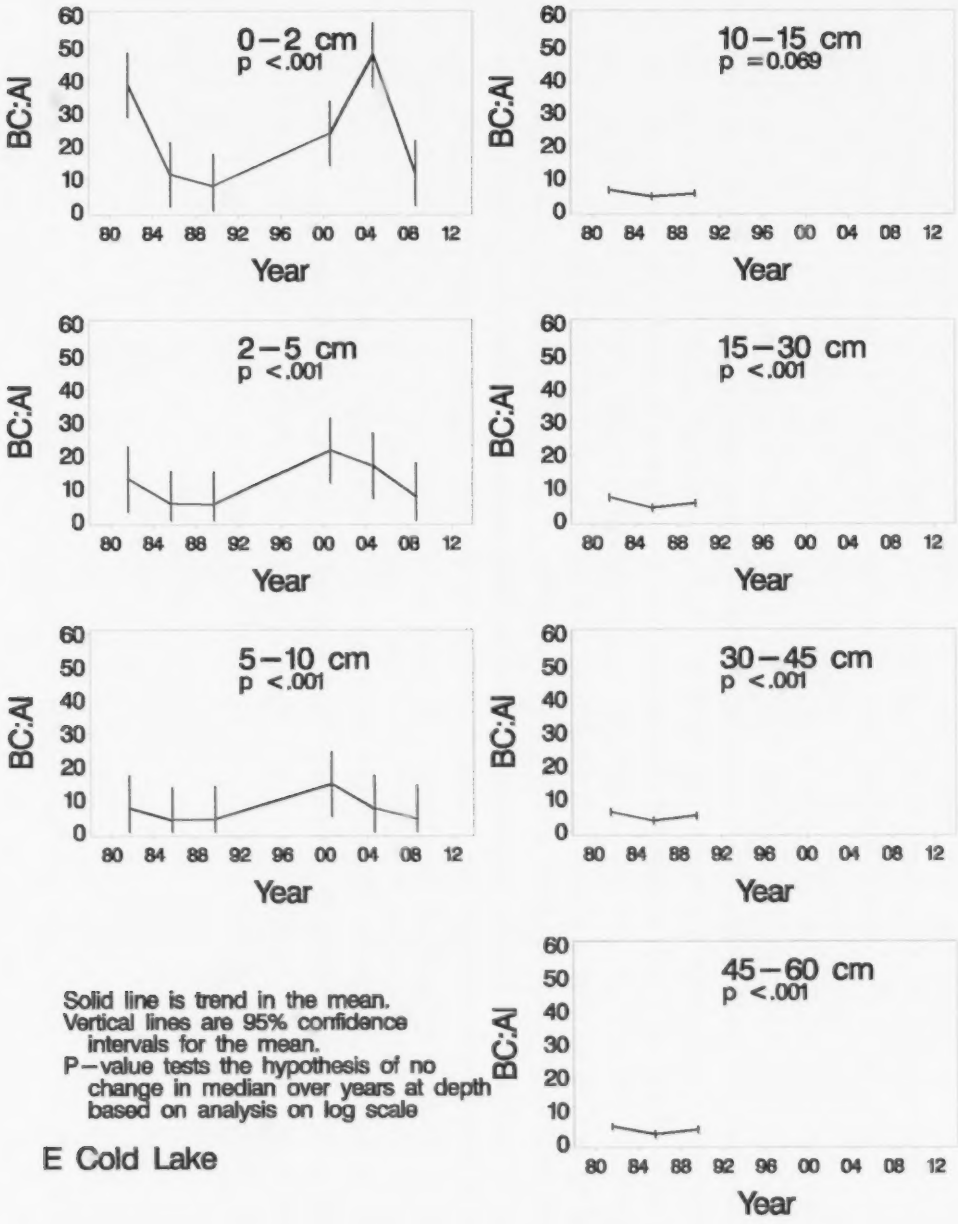
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

N Fort Mcmurray



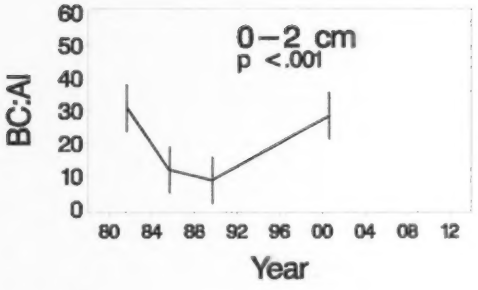
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

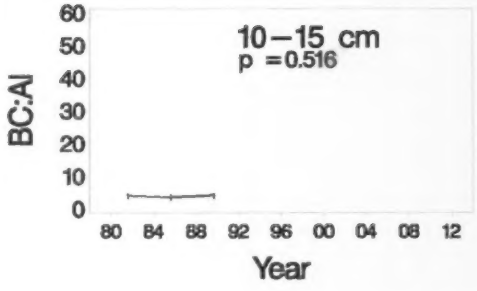
S Fort Mcmurray

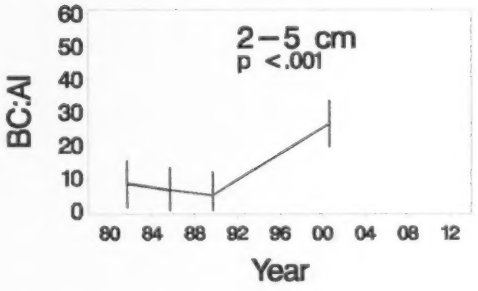


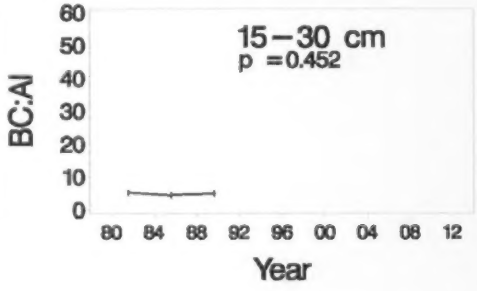
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

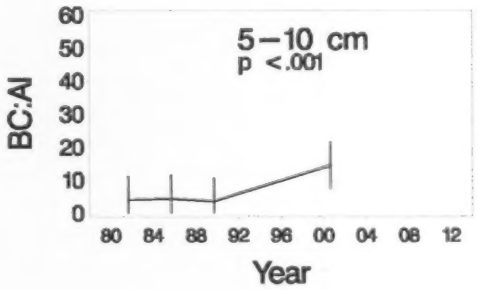
E Cold Lake

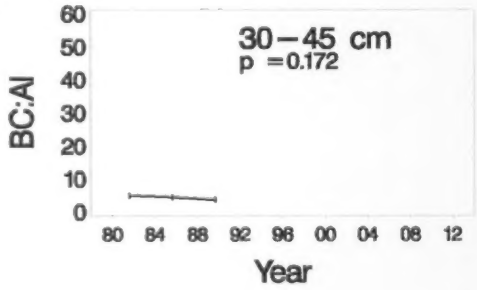




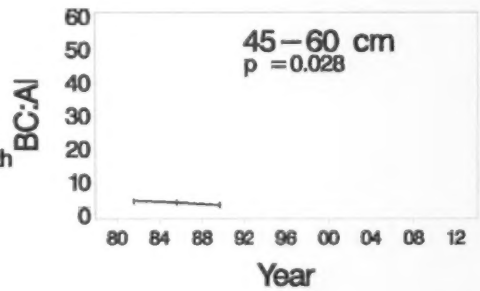




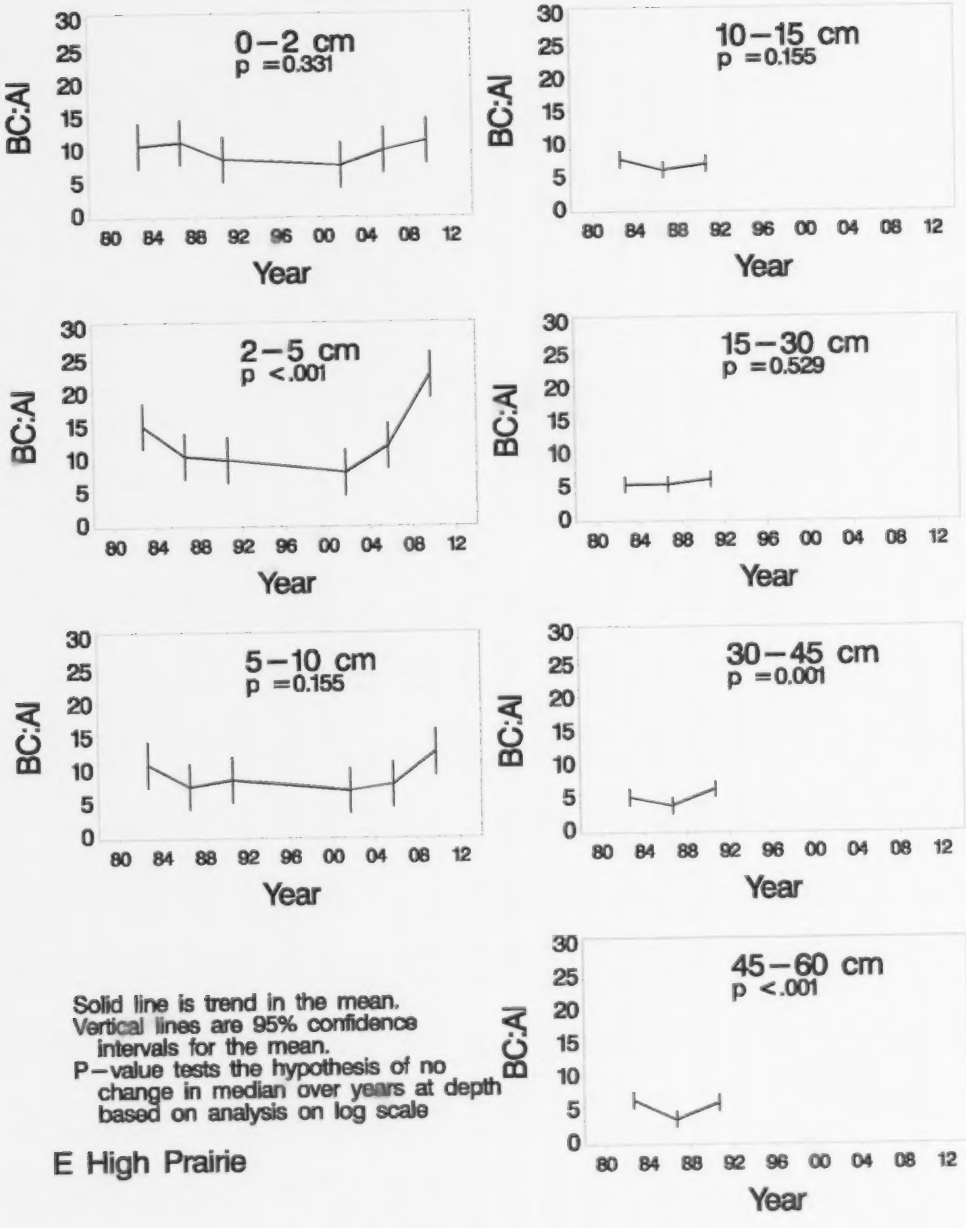




Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale



W Cold Lake



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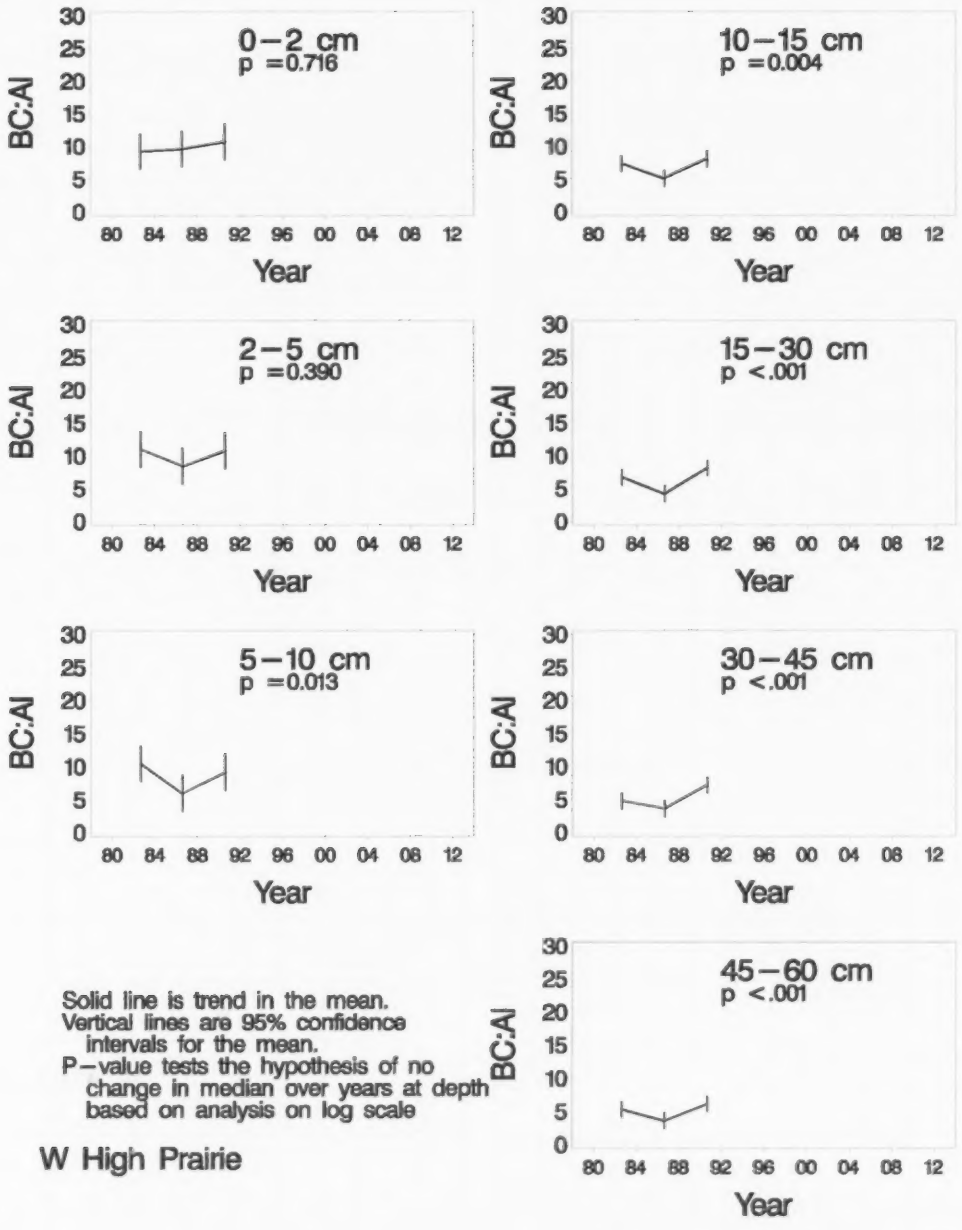
E High Prairie



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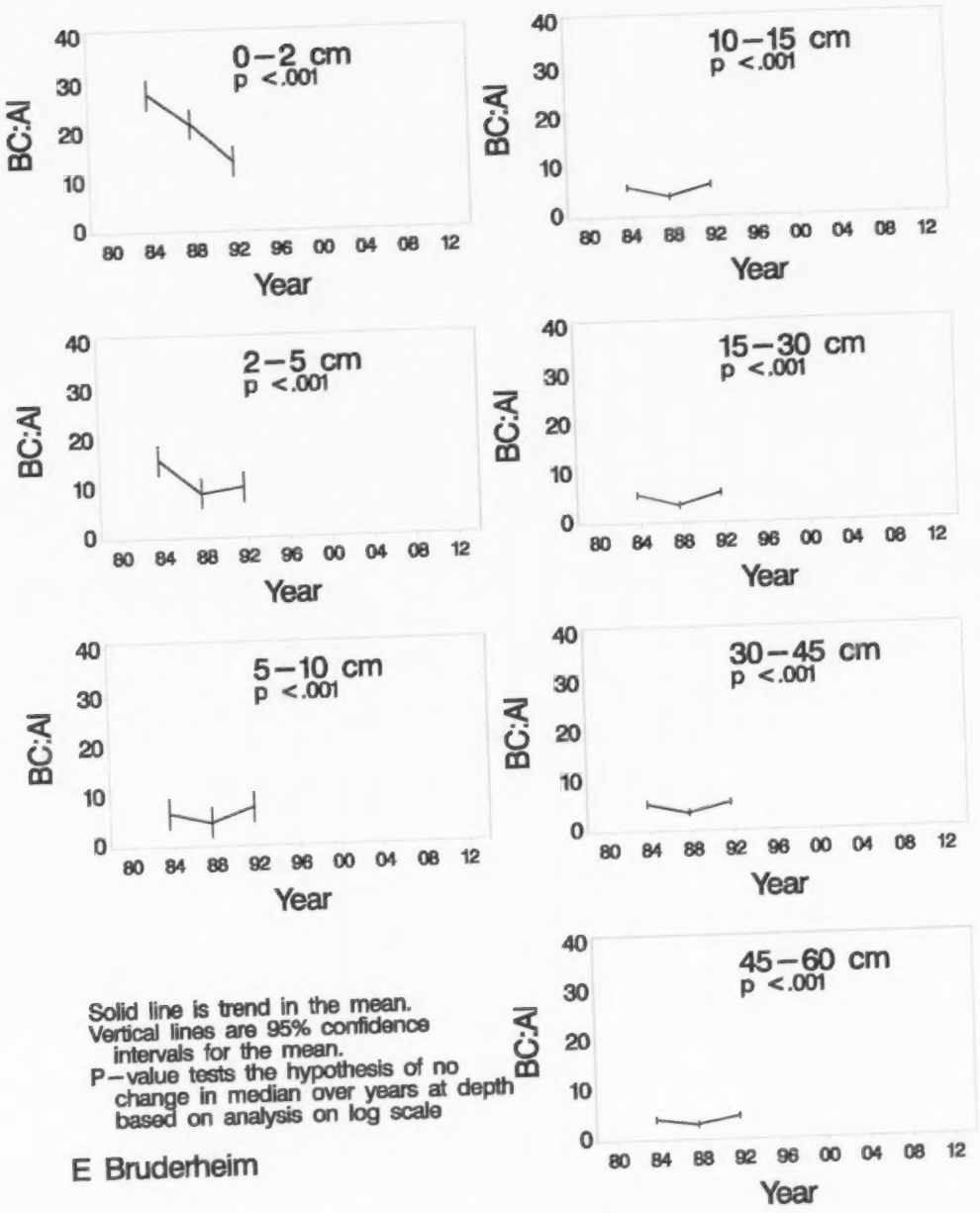
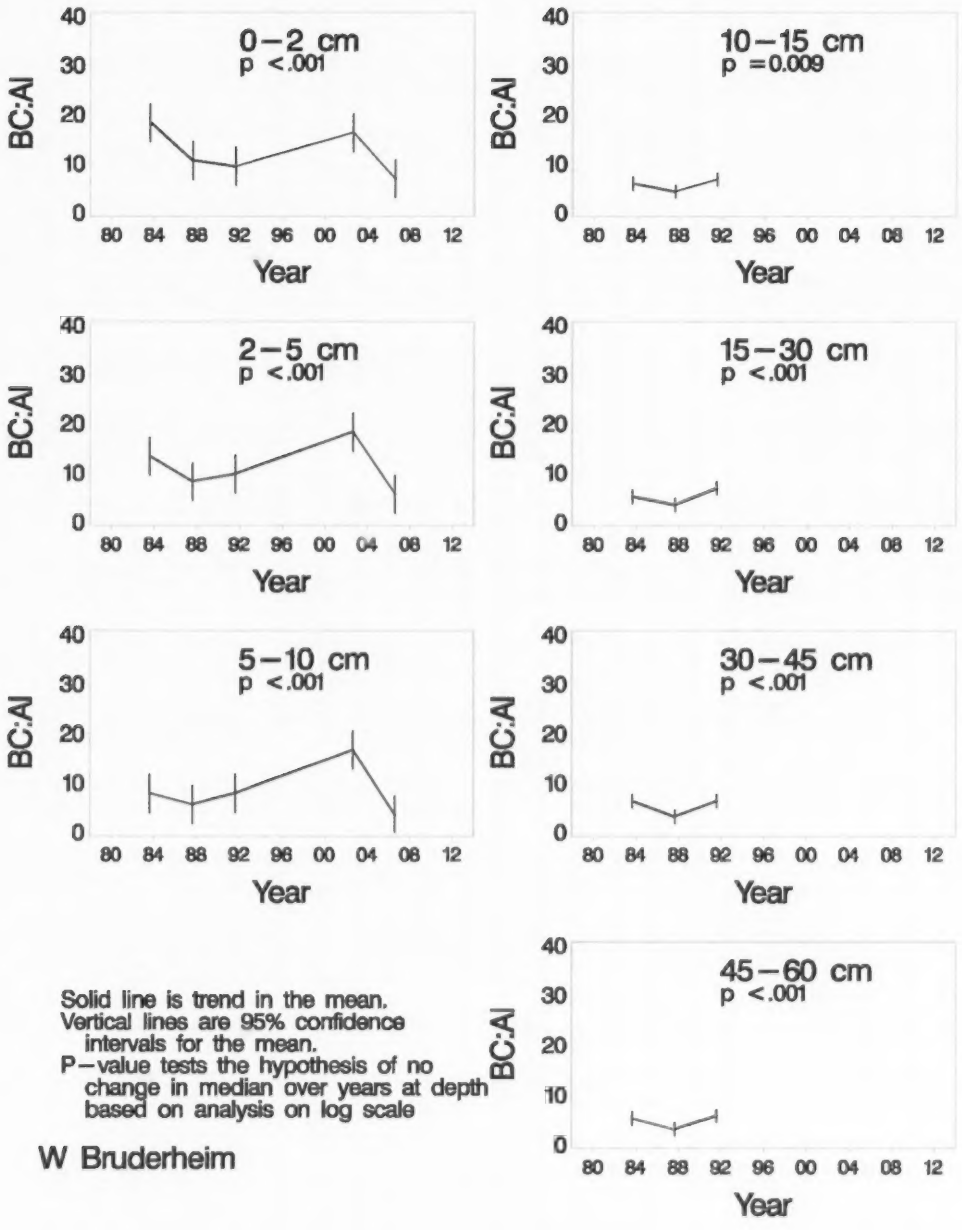
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

W High Prairie



Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

E Bruderheim



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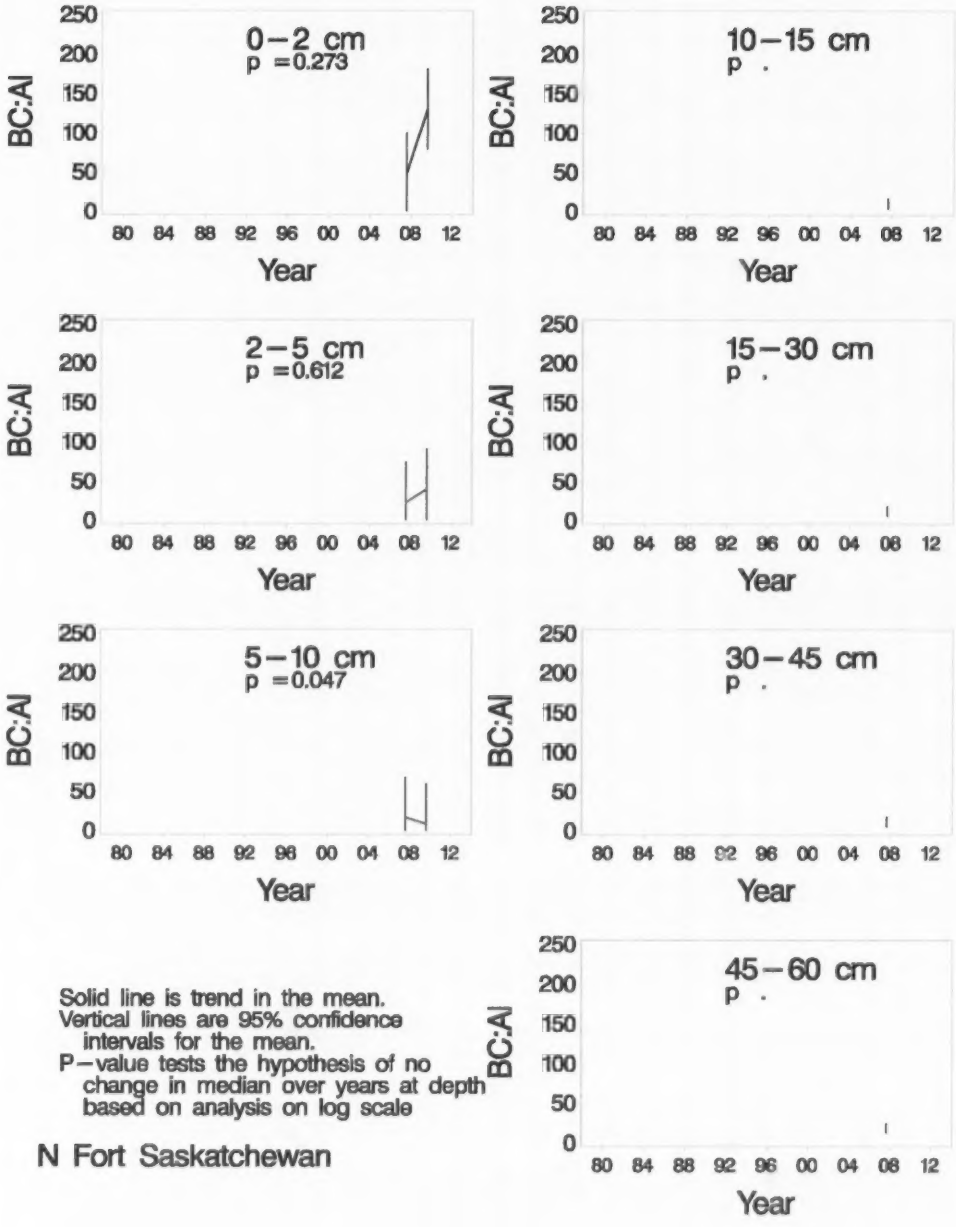
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

W Bruderheim



Solid line is trend in the mean.
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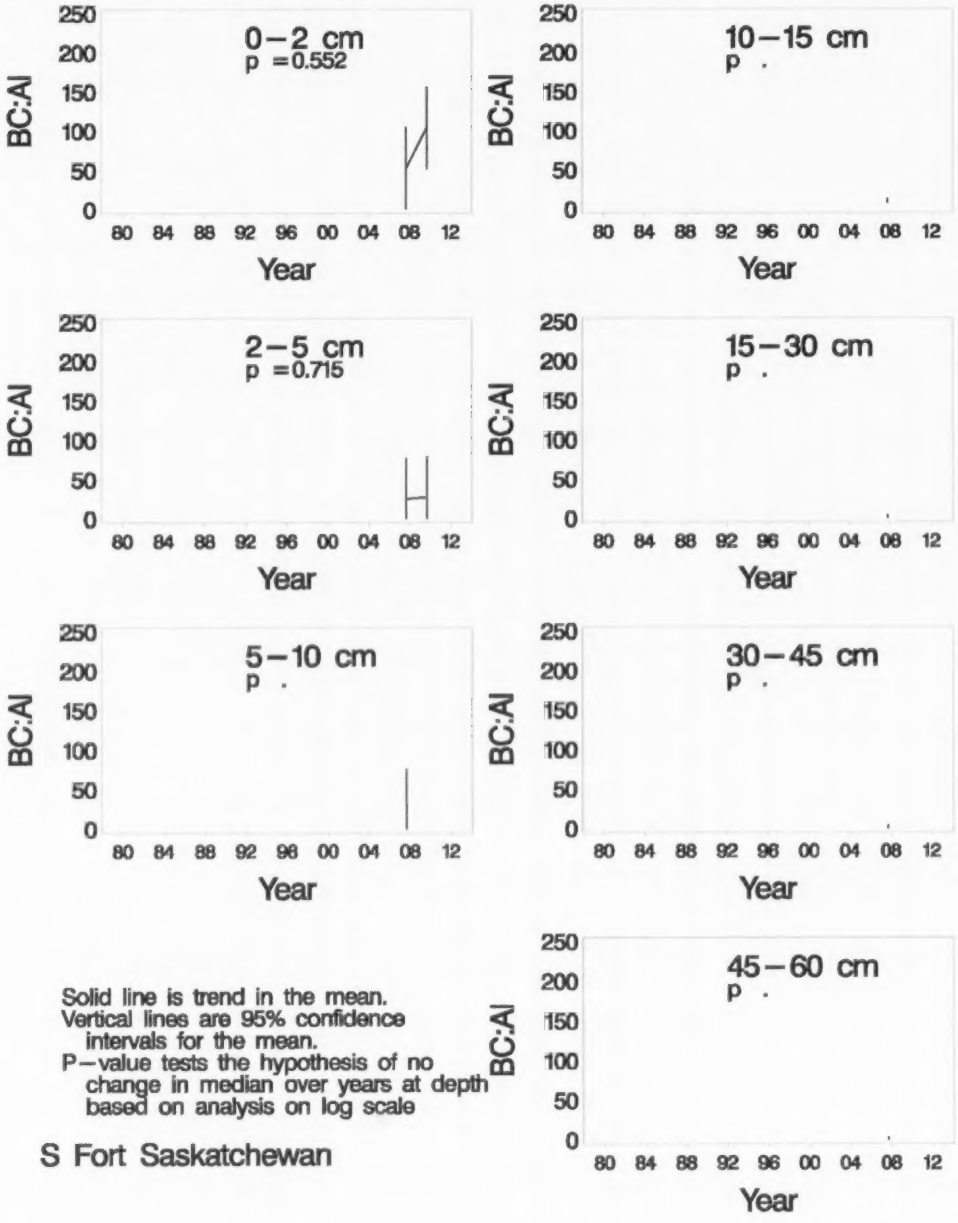
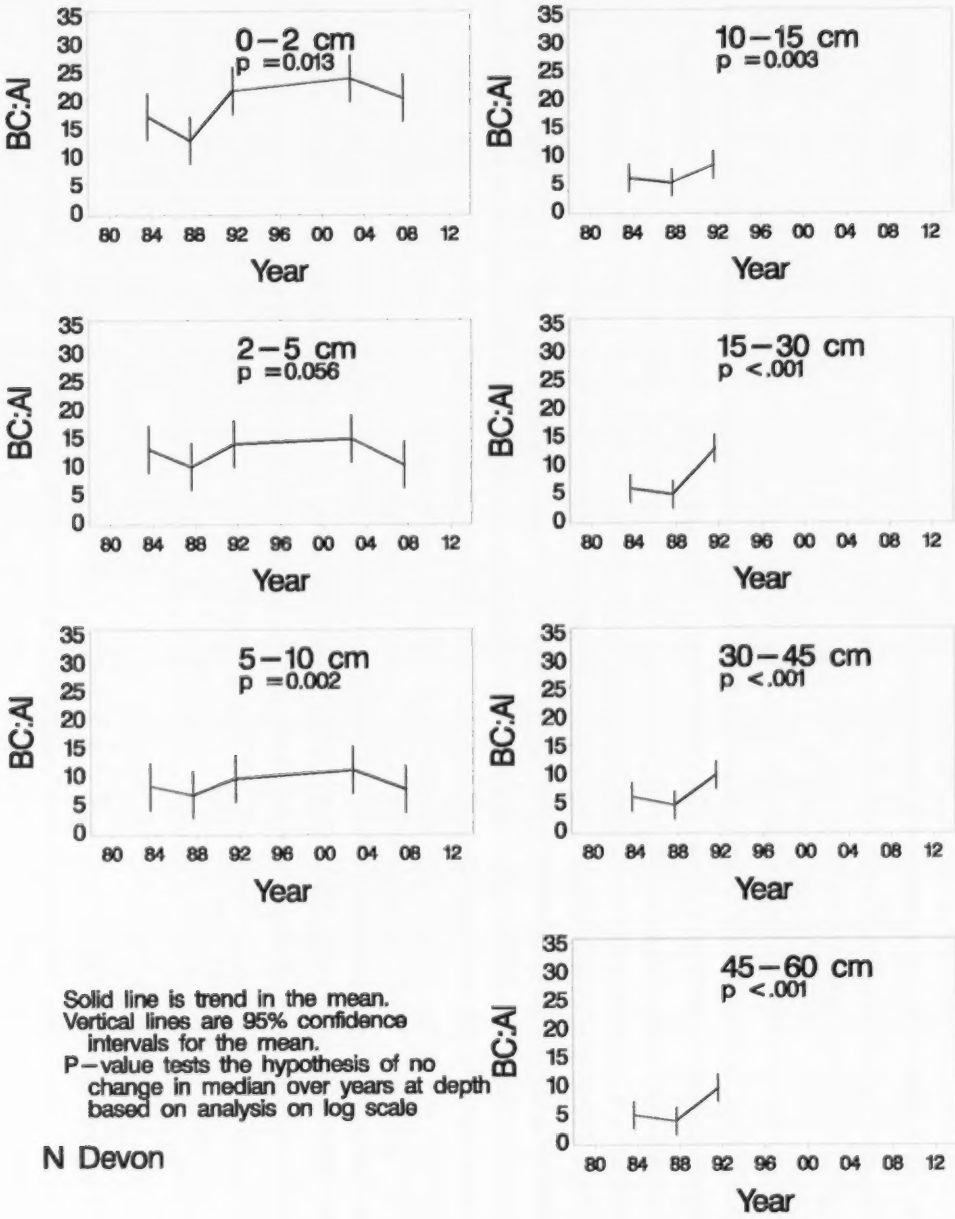
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

N Fort Saskatchewan



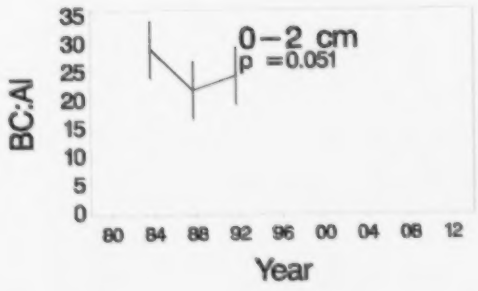
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

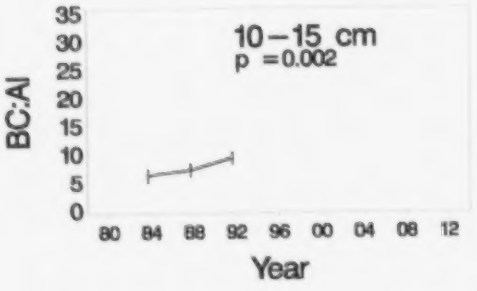
S Fort Saskatchewan

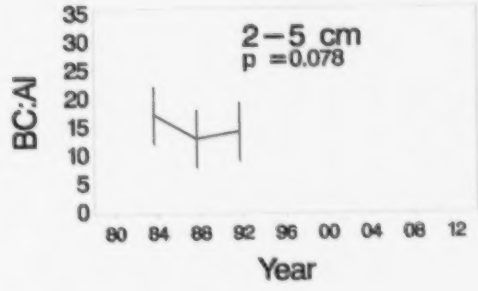


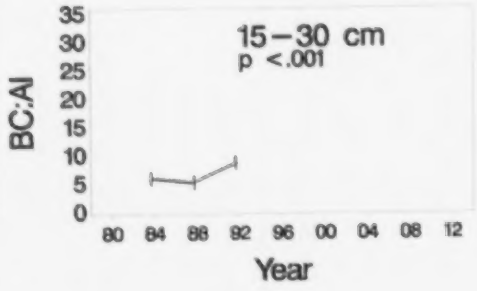
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

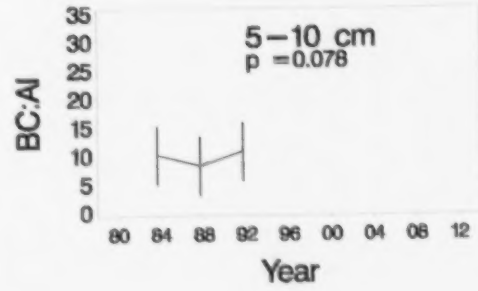
N Devon

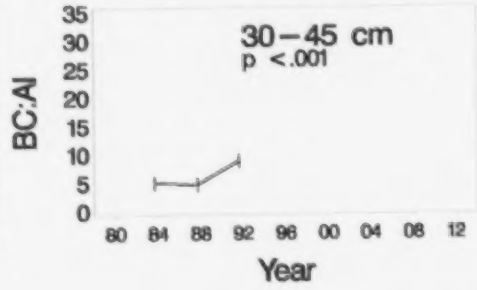


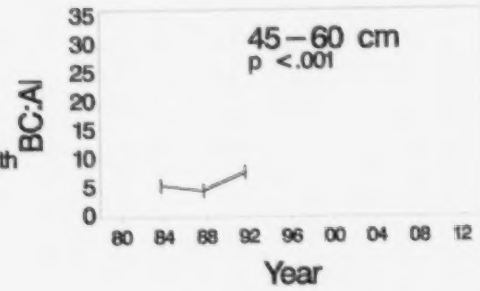












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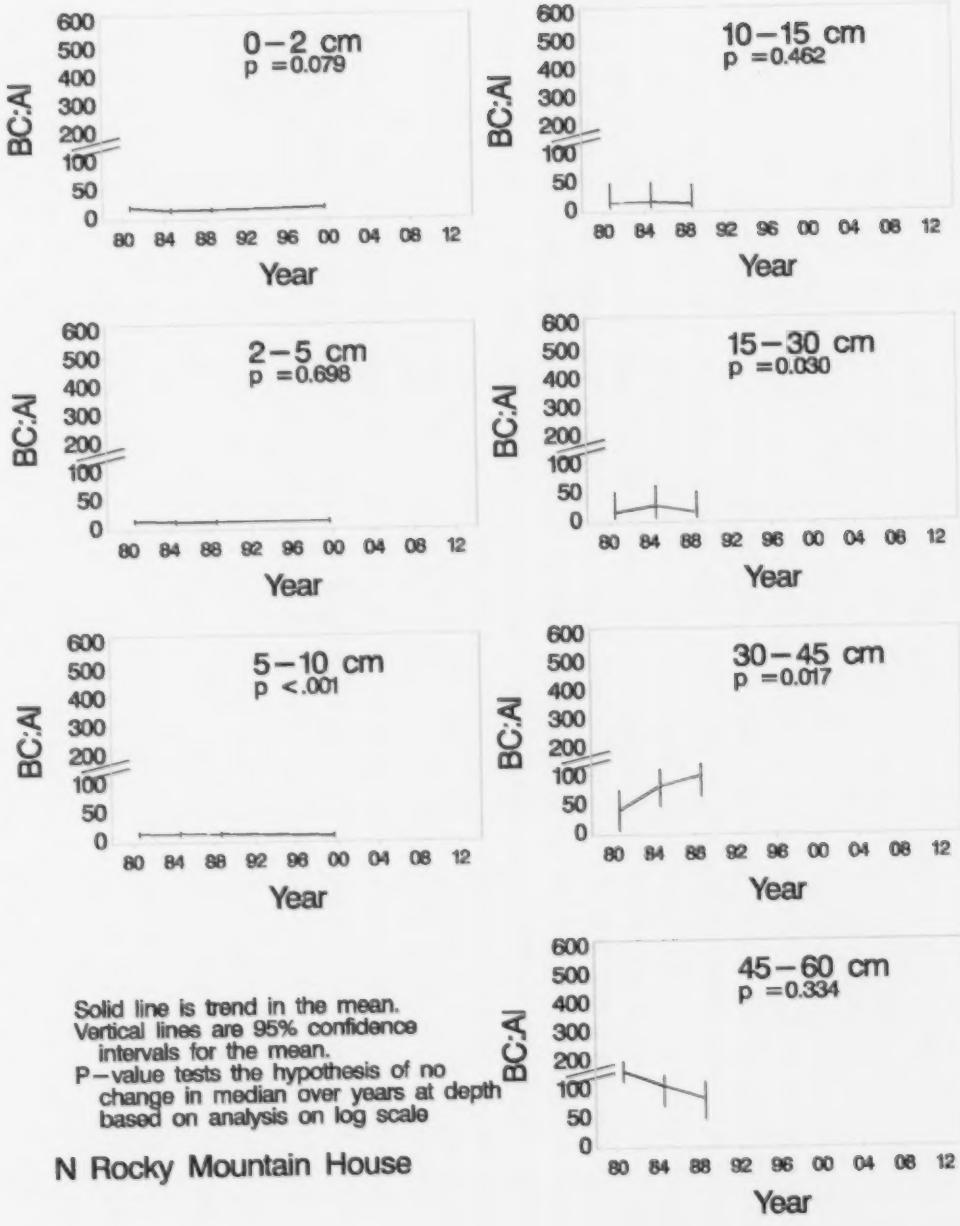
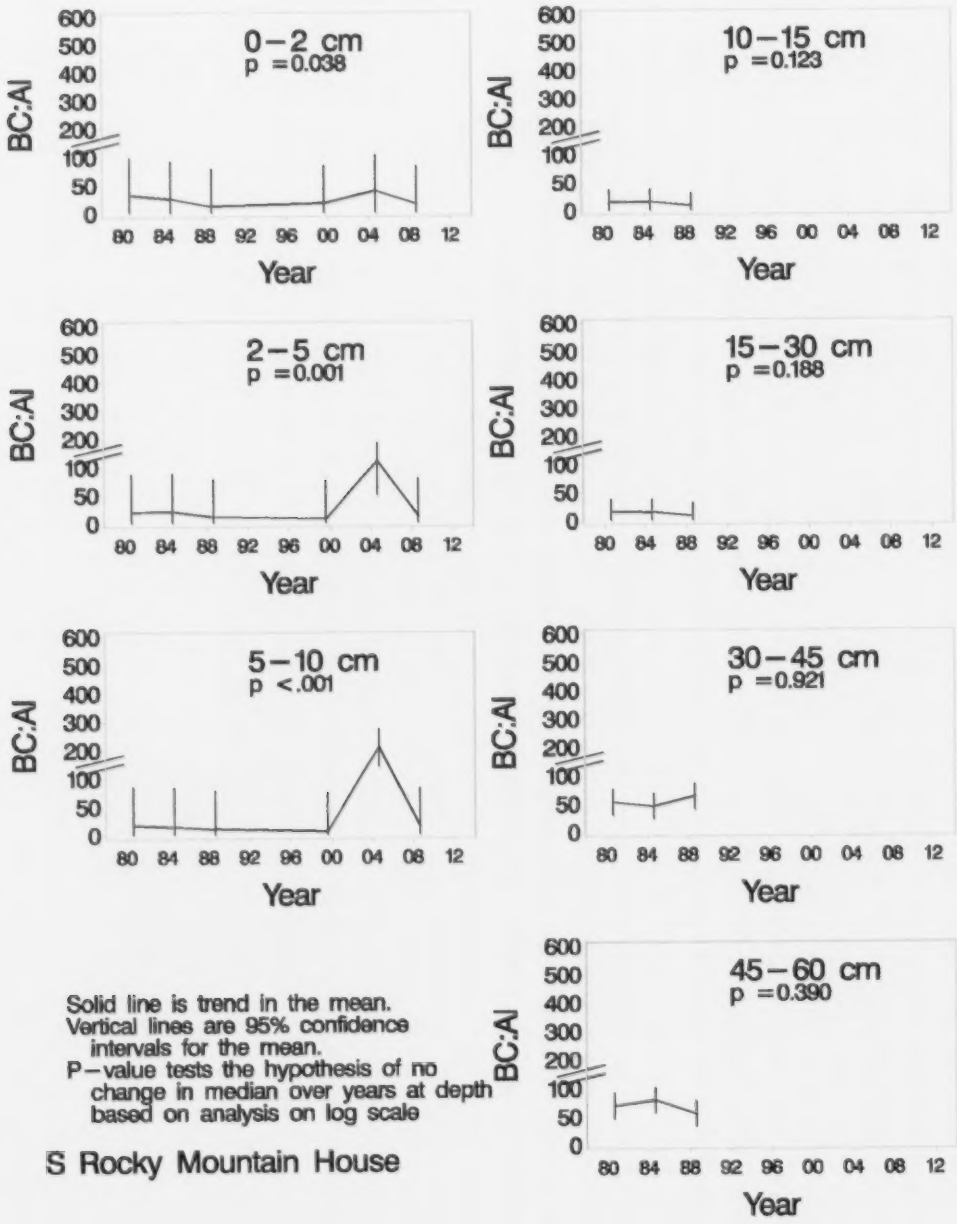
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

S Devon



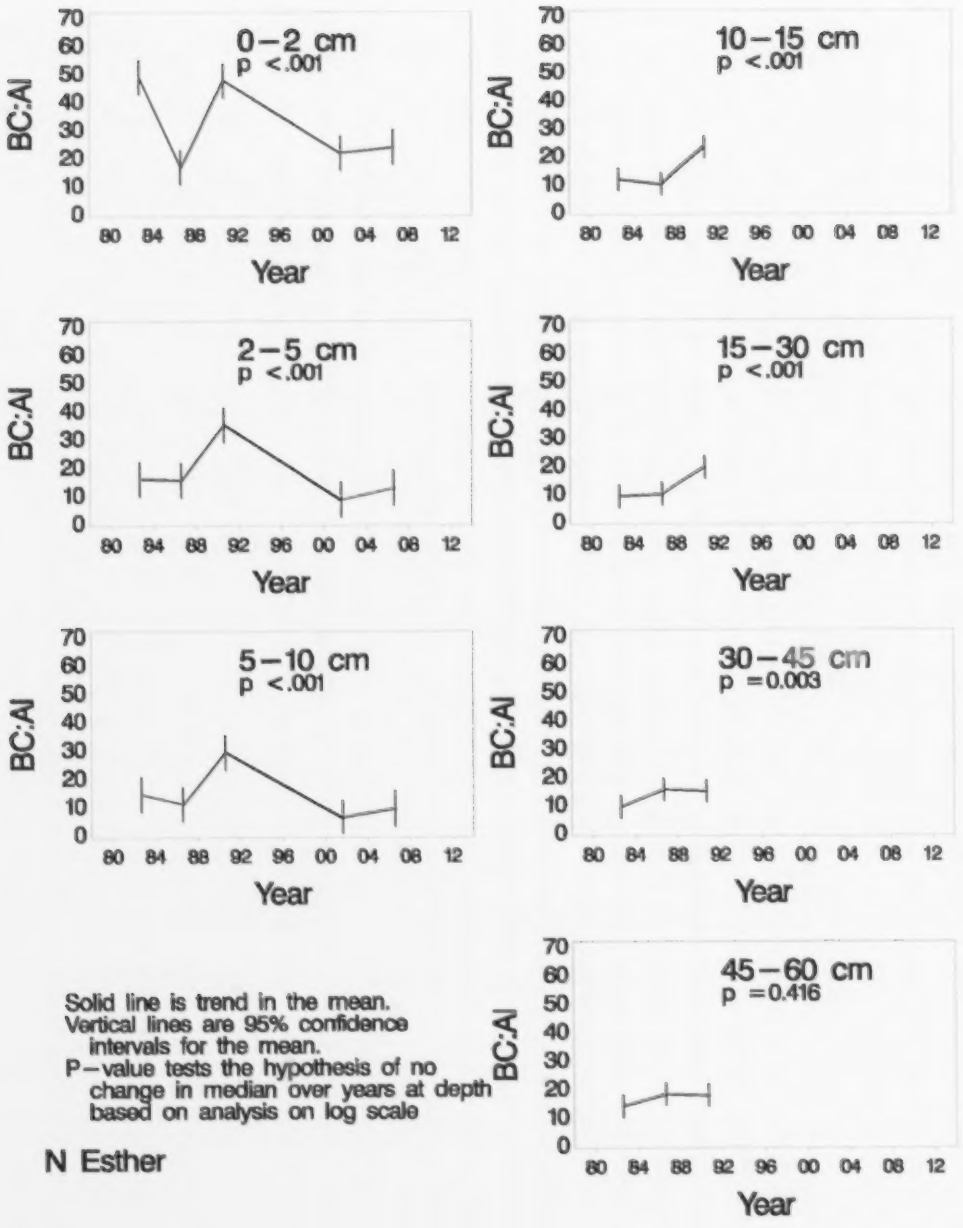
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

N Rocky Mountain House



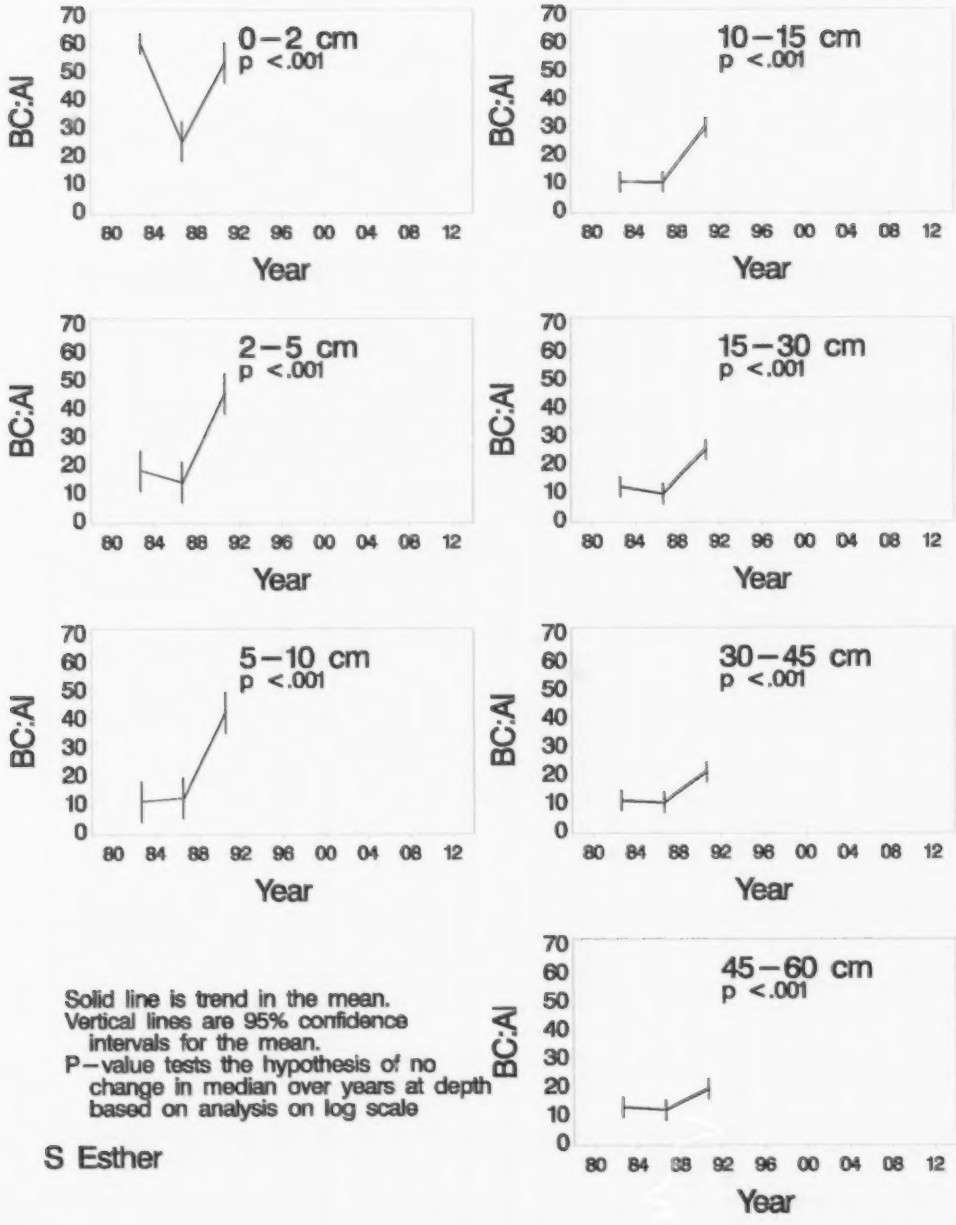
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

S Rocky Mountain House



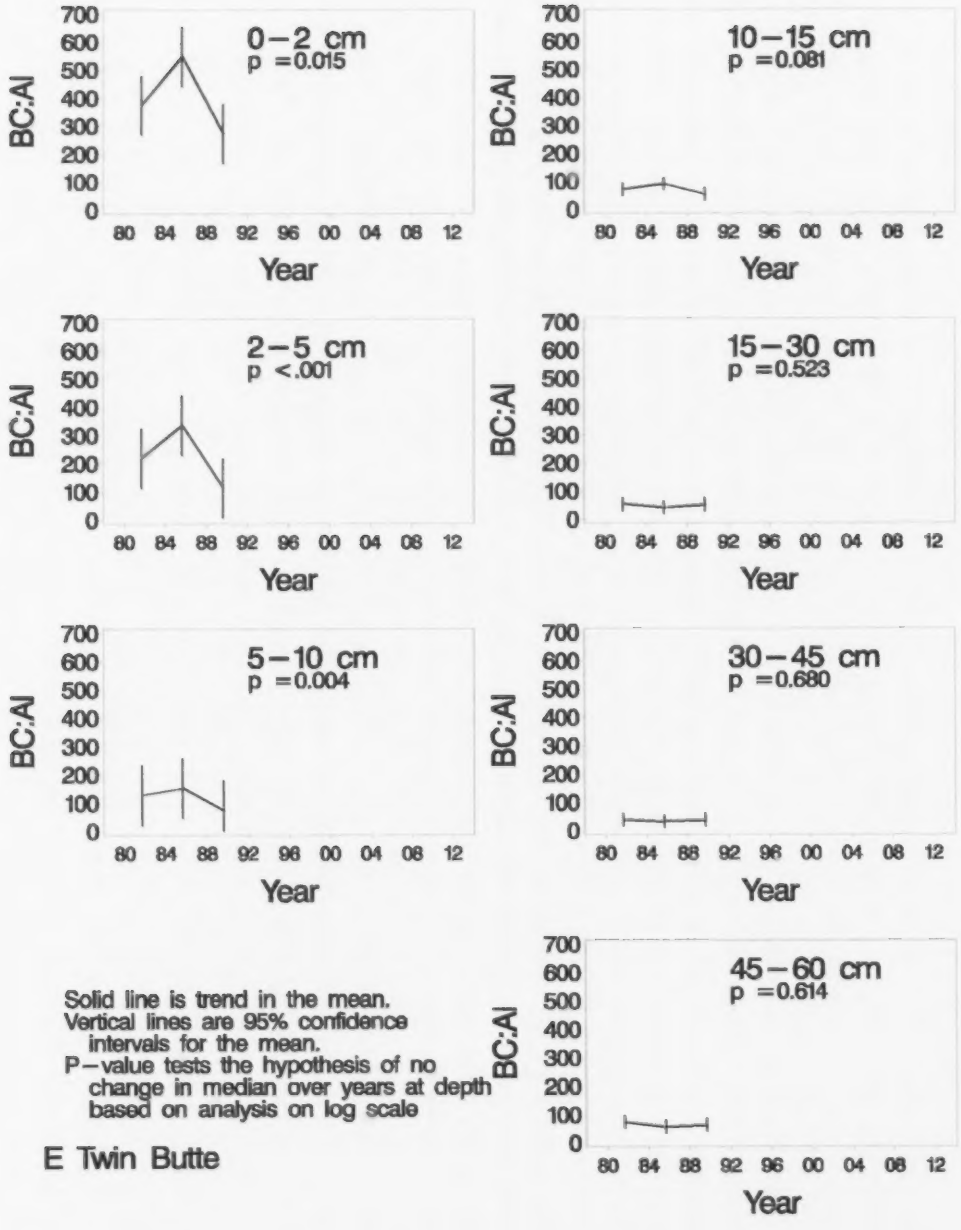
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

N Esther



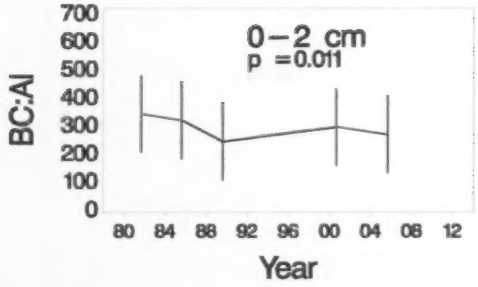
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

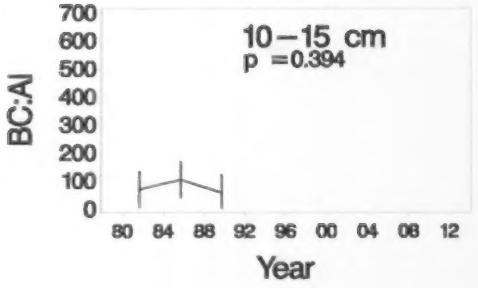
S Esther

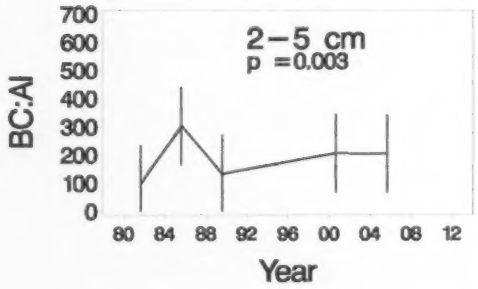


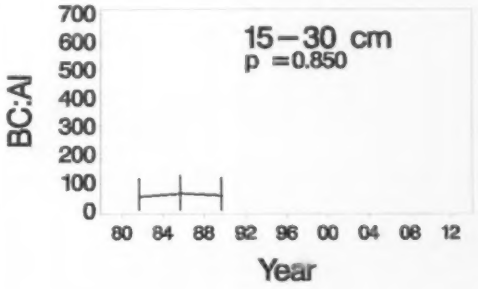
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale

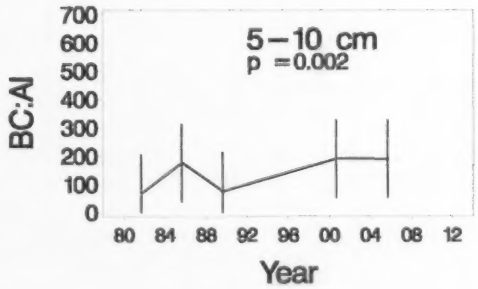
E Twin Butte

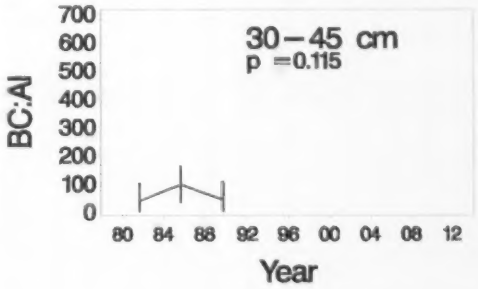












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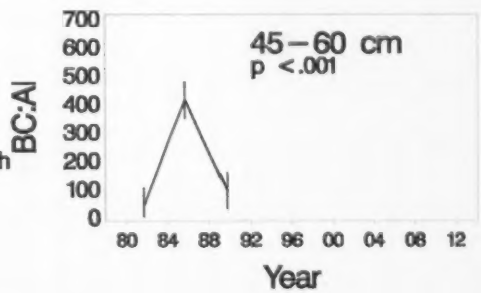
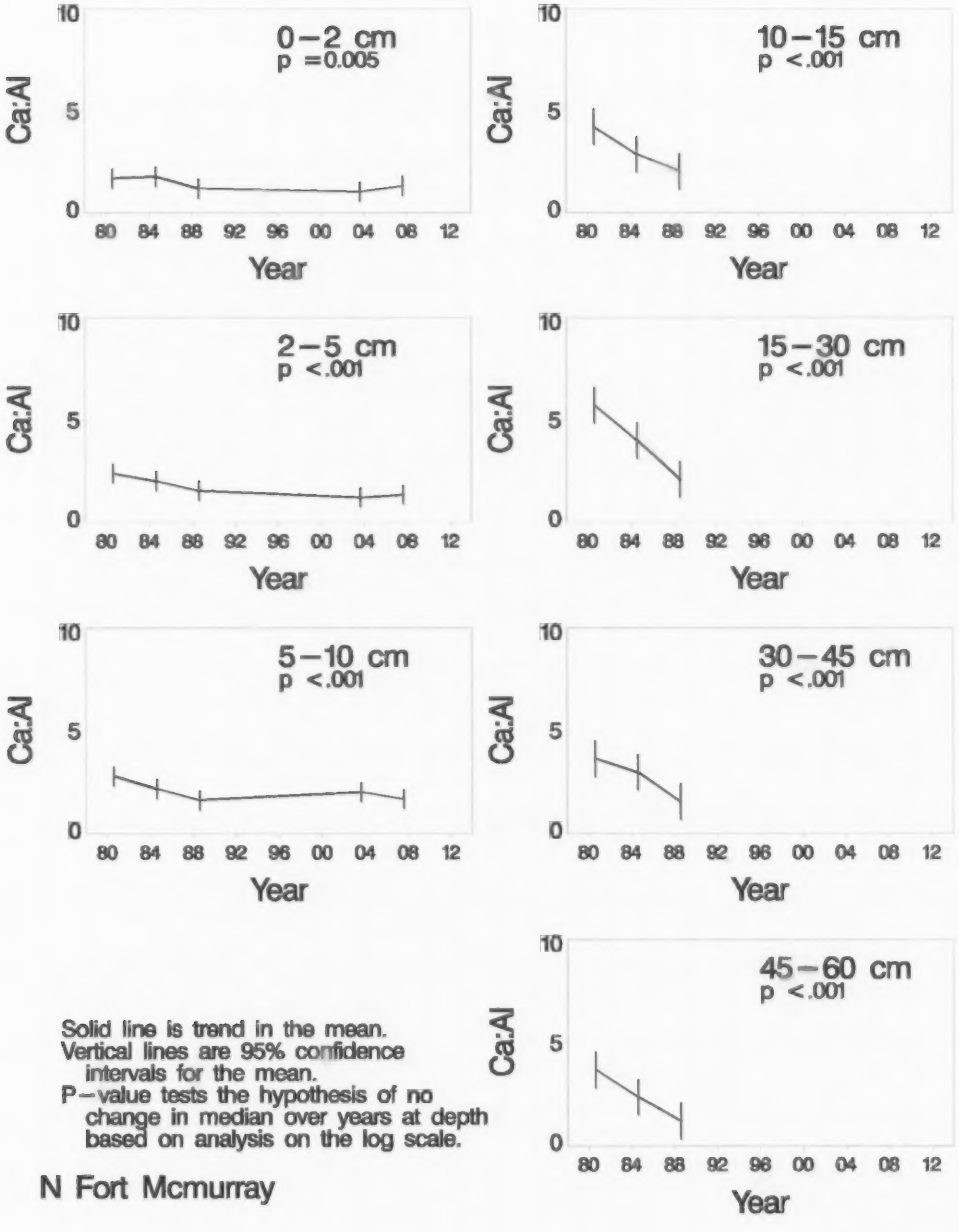
P–value tests the hypothesis of no change in median over years at depth based on analysis on log scale



W Twin Butte

APPENDIX C4

GRAPHICAL PRESENTATION OF BASE CATION:ALUMINUM (BC:AL) RATIO AT ALL SITES



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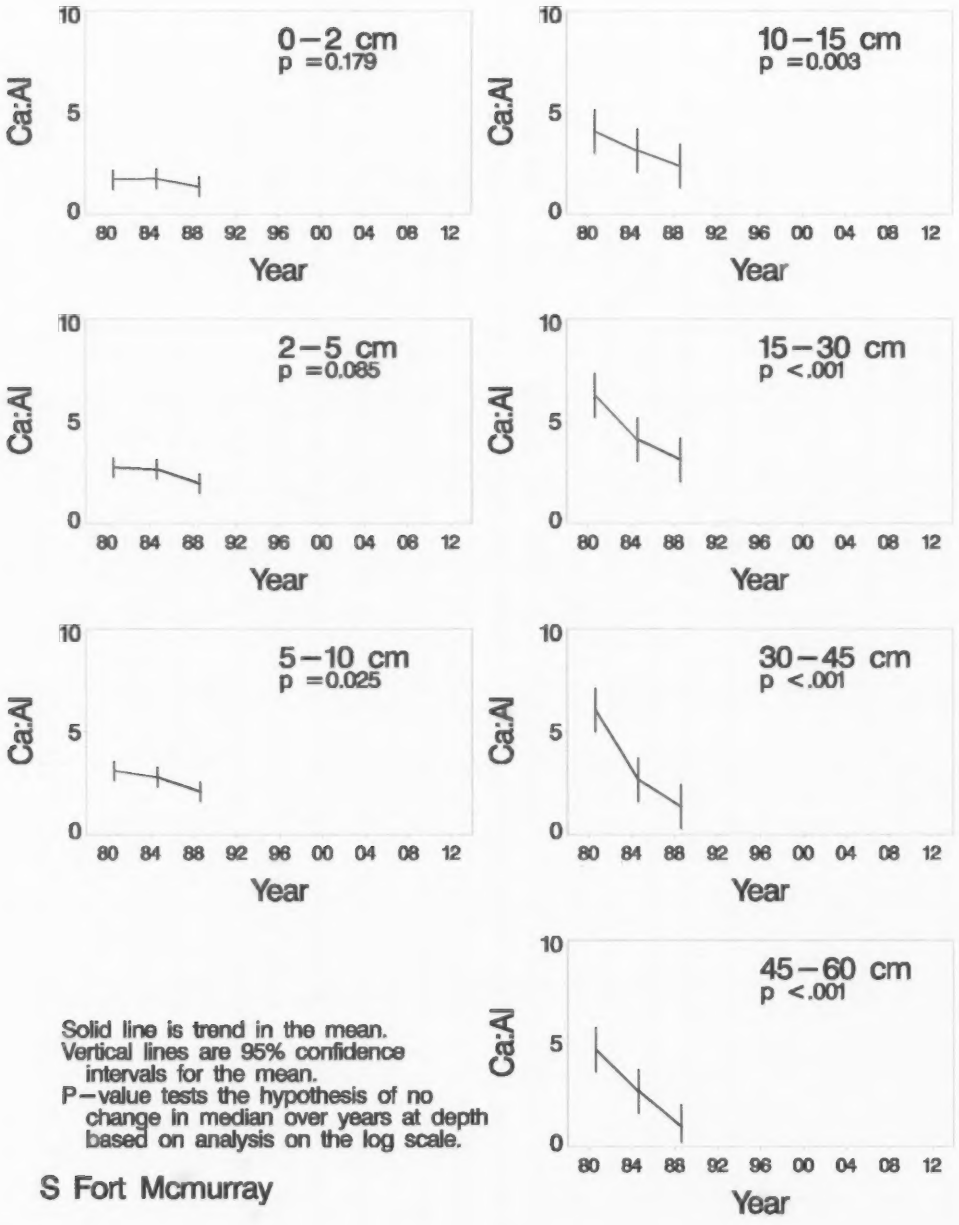
P–value tests the hypothesis of no change in median over years at depth based on analysis on the log scale.

N Fort Mcmurray



Solid line is trend in the mean.
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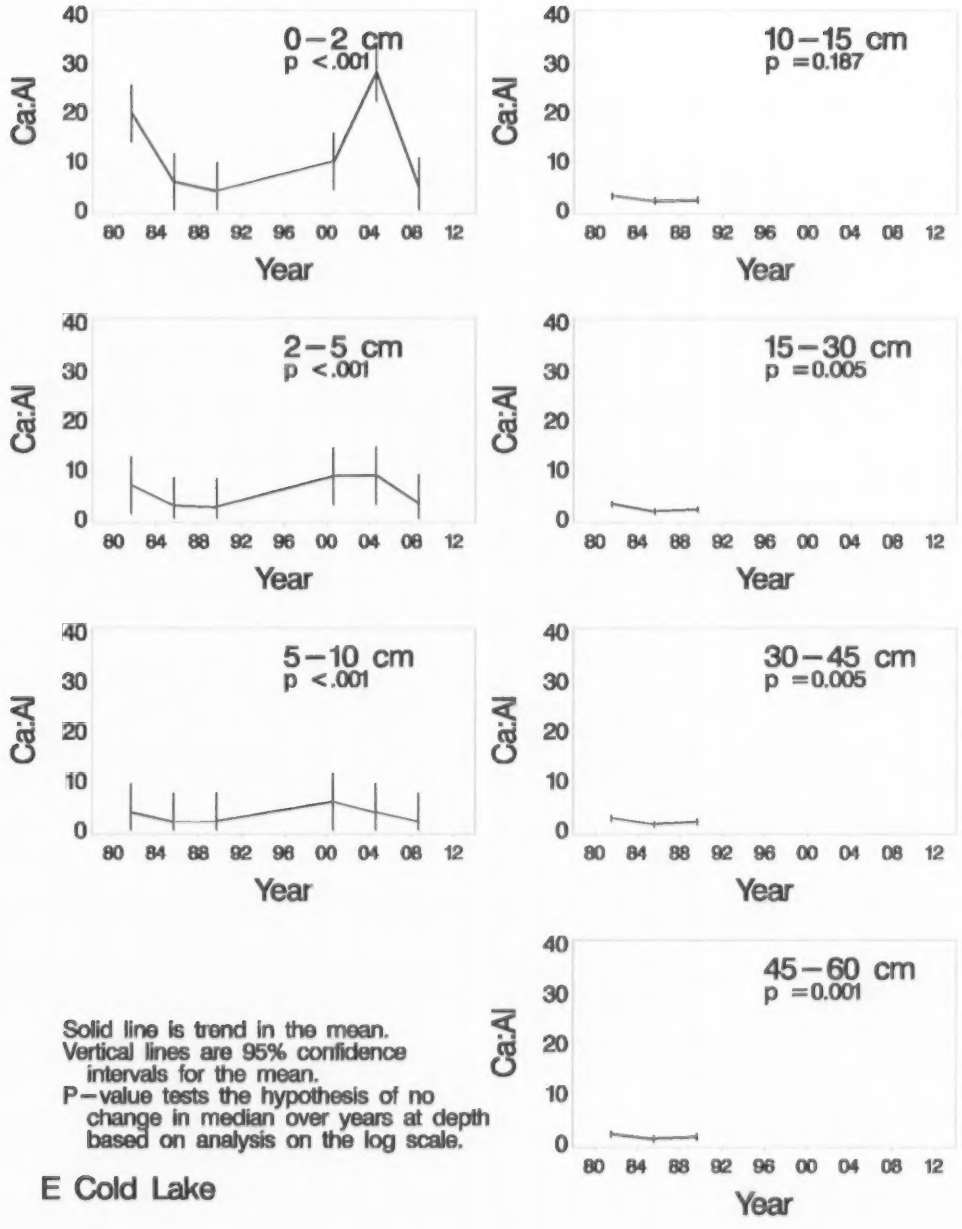
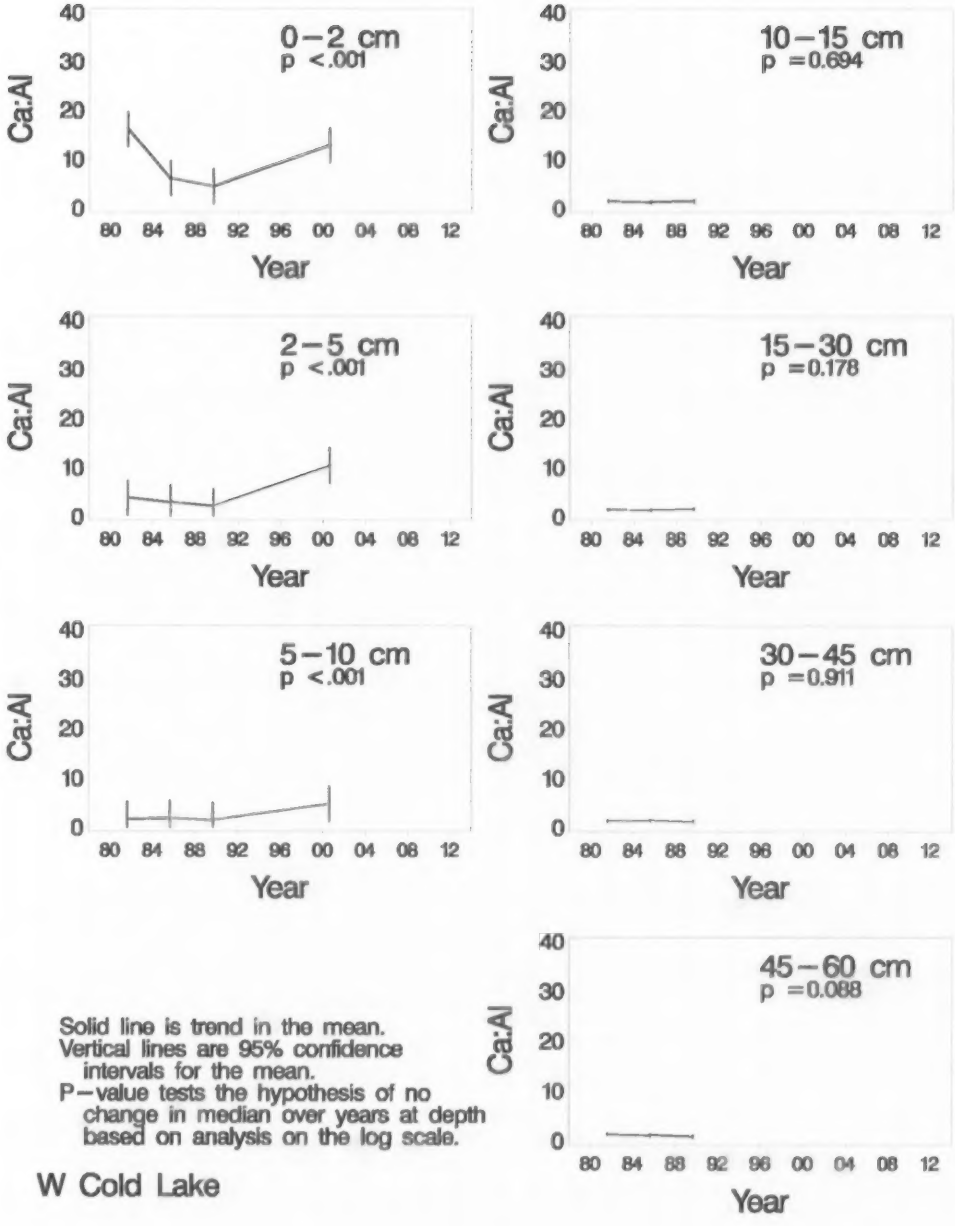
P–value tests the hypothesis of no change in median over years at depth based on analysis on the log scale.

S Fort Mcmurray



Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on the log scale.

E Cold Lake



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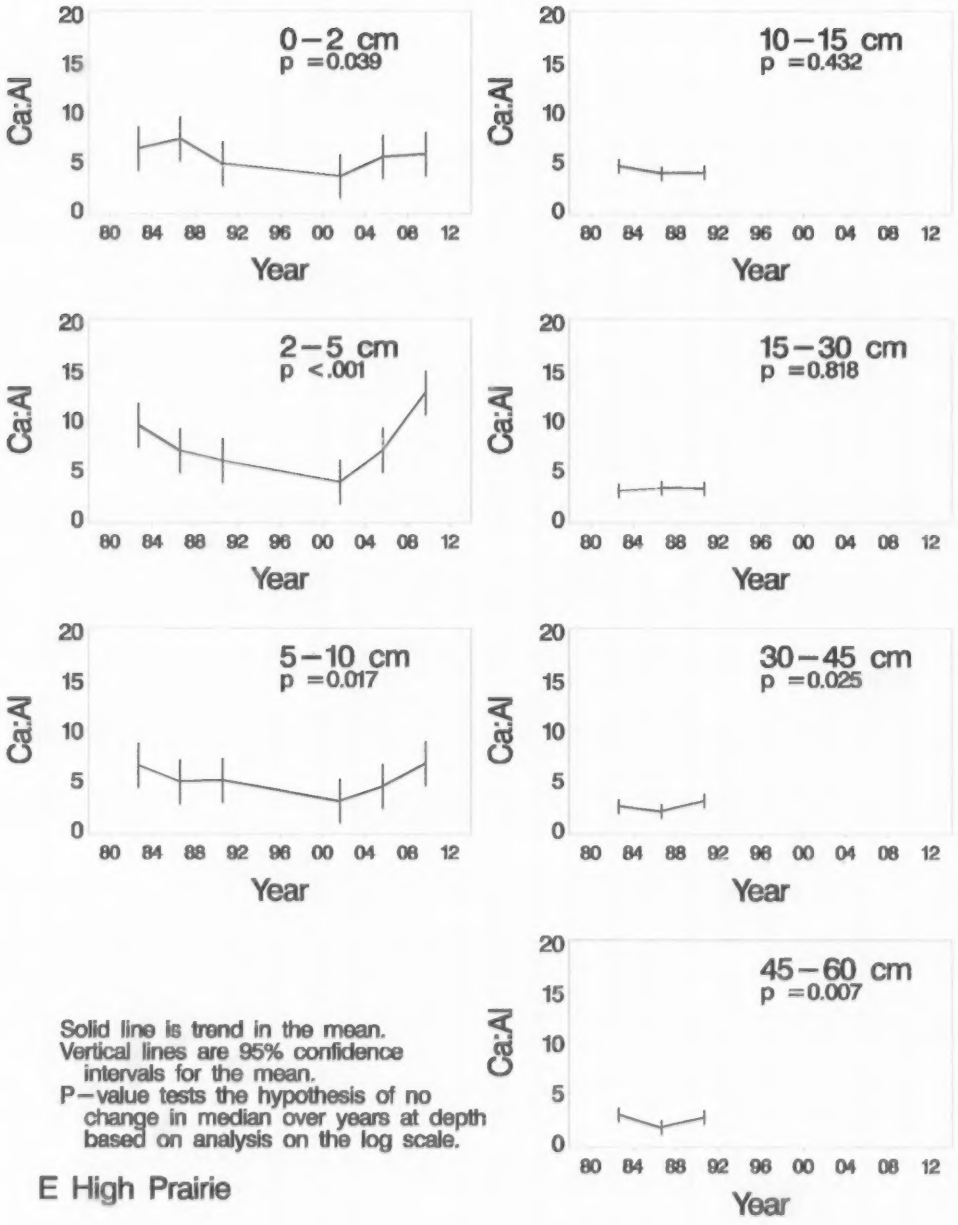
W Cold Lake



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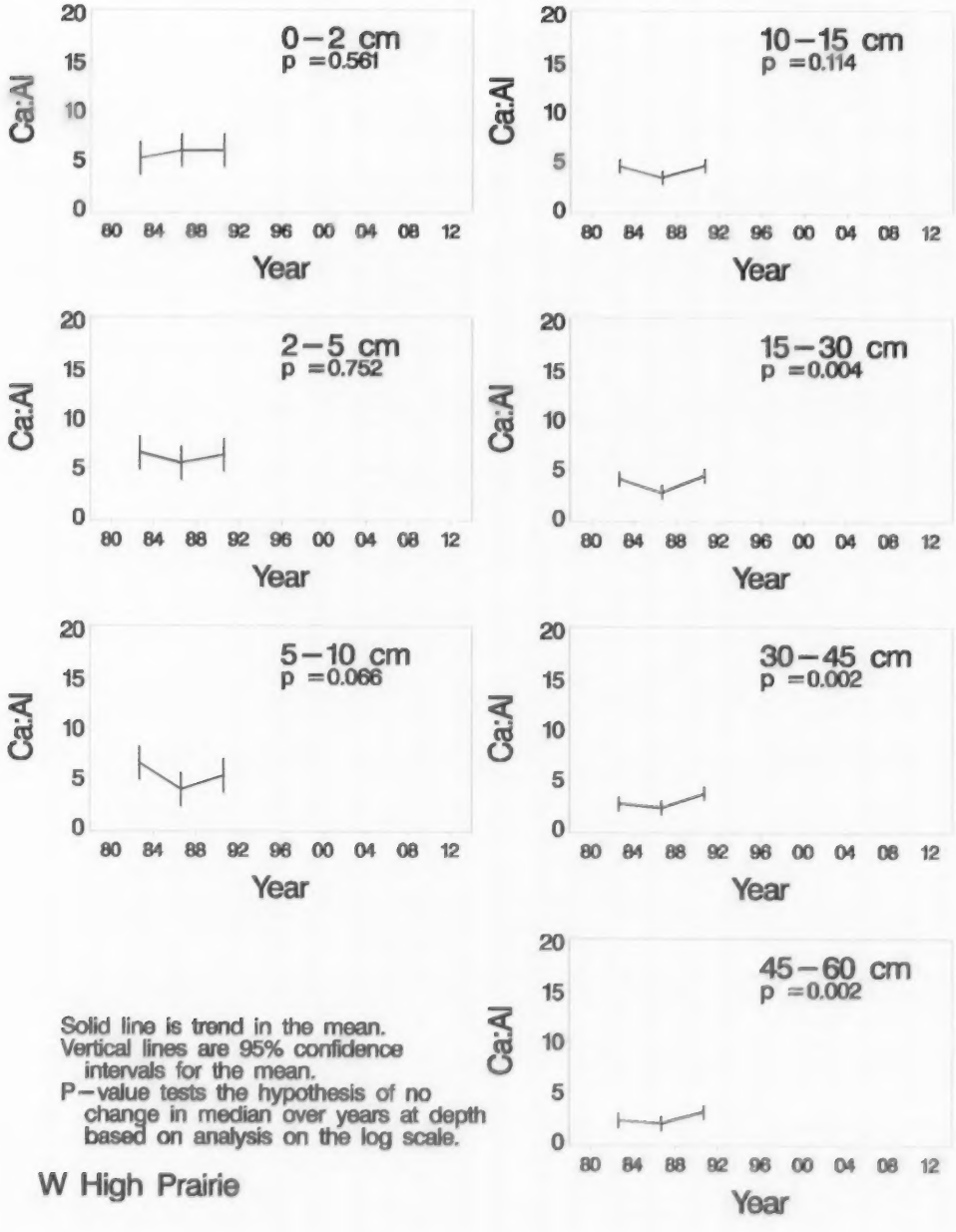
E High Prairie



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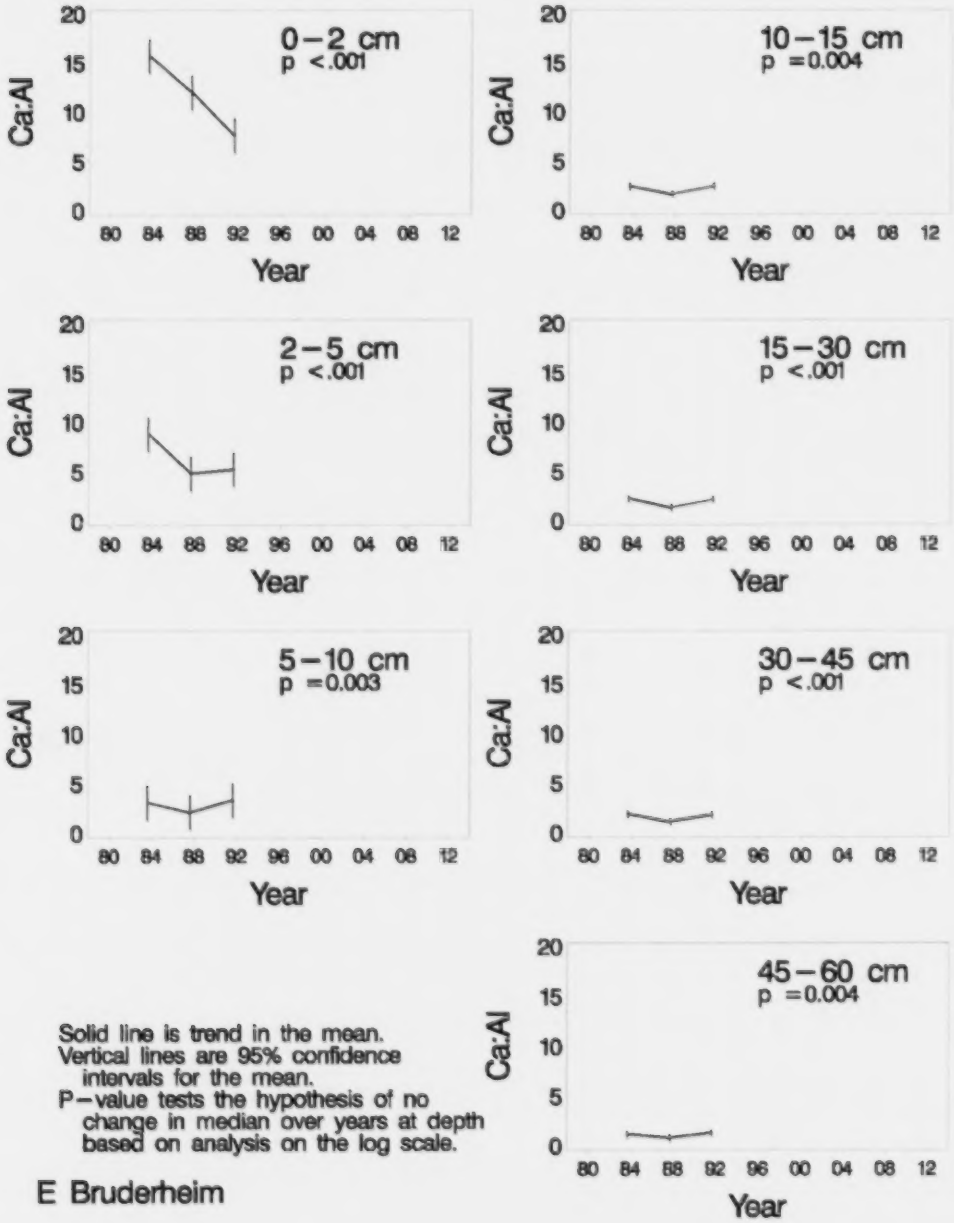
W High Prairie



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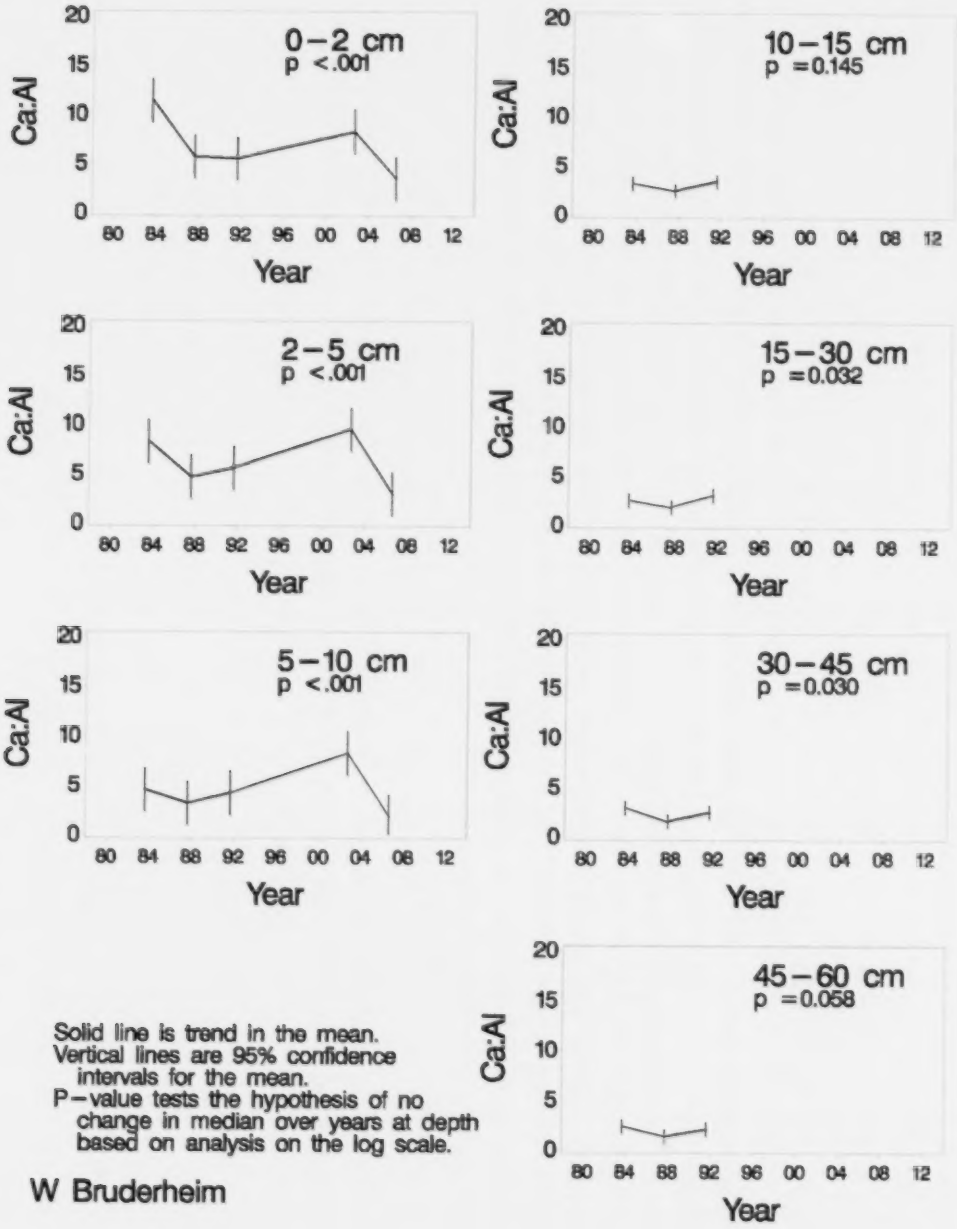
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on the log scale.

E Bruderheim



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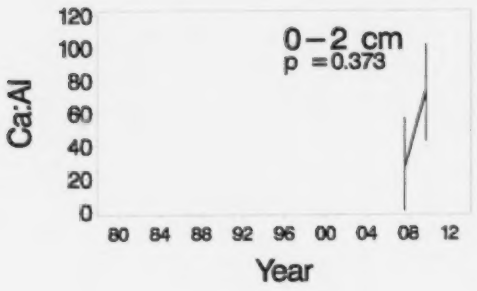
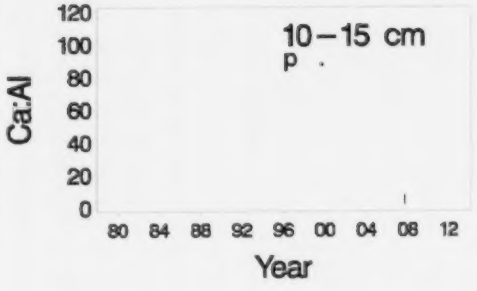
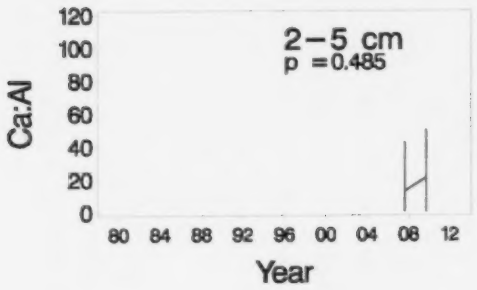
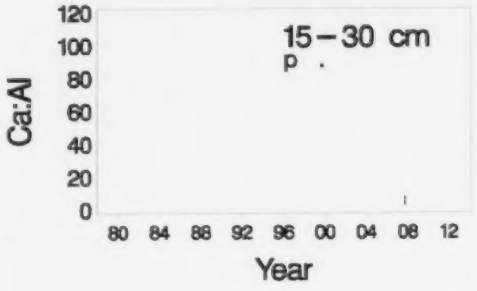
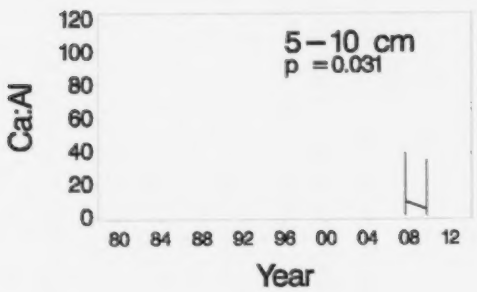
W Bruderheim

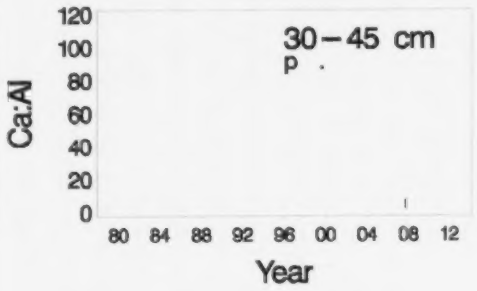


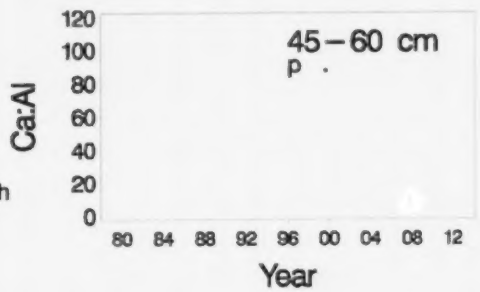












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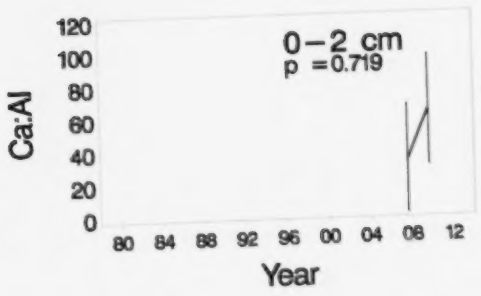
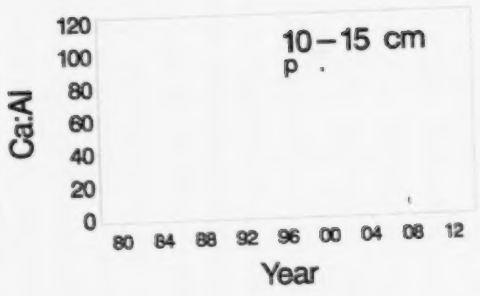
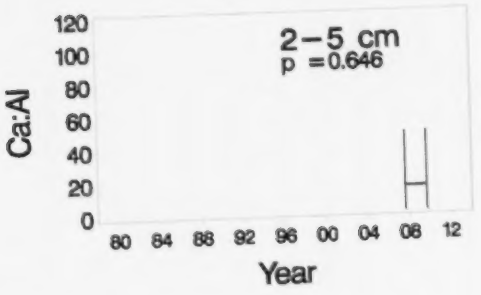
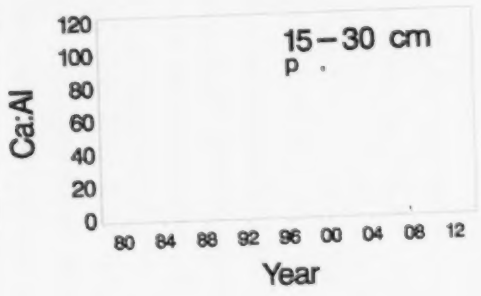
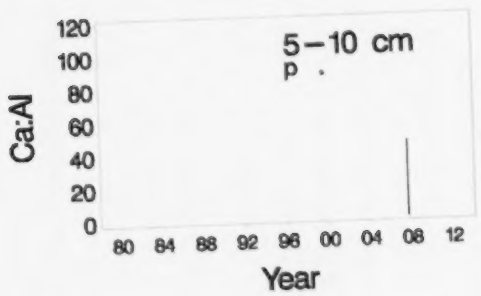
N Fort Saskatchewan

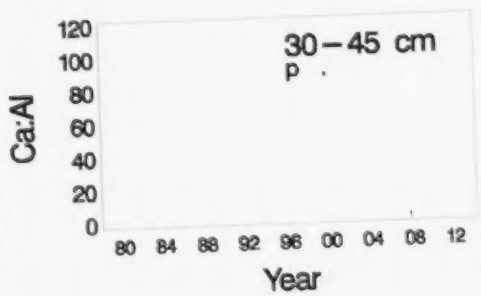


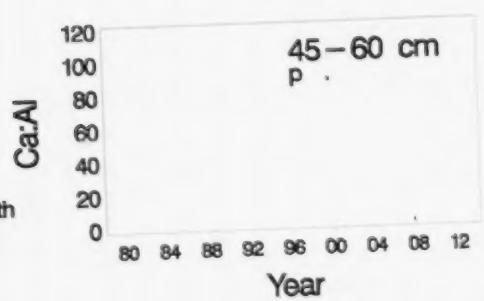






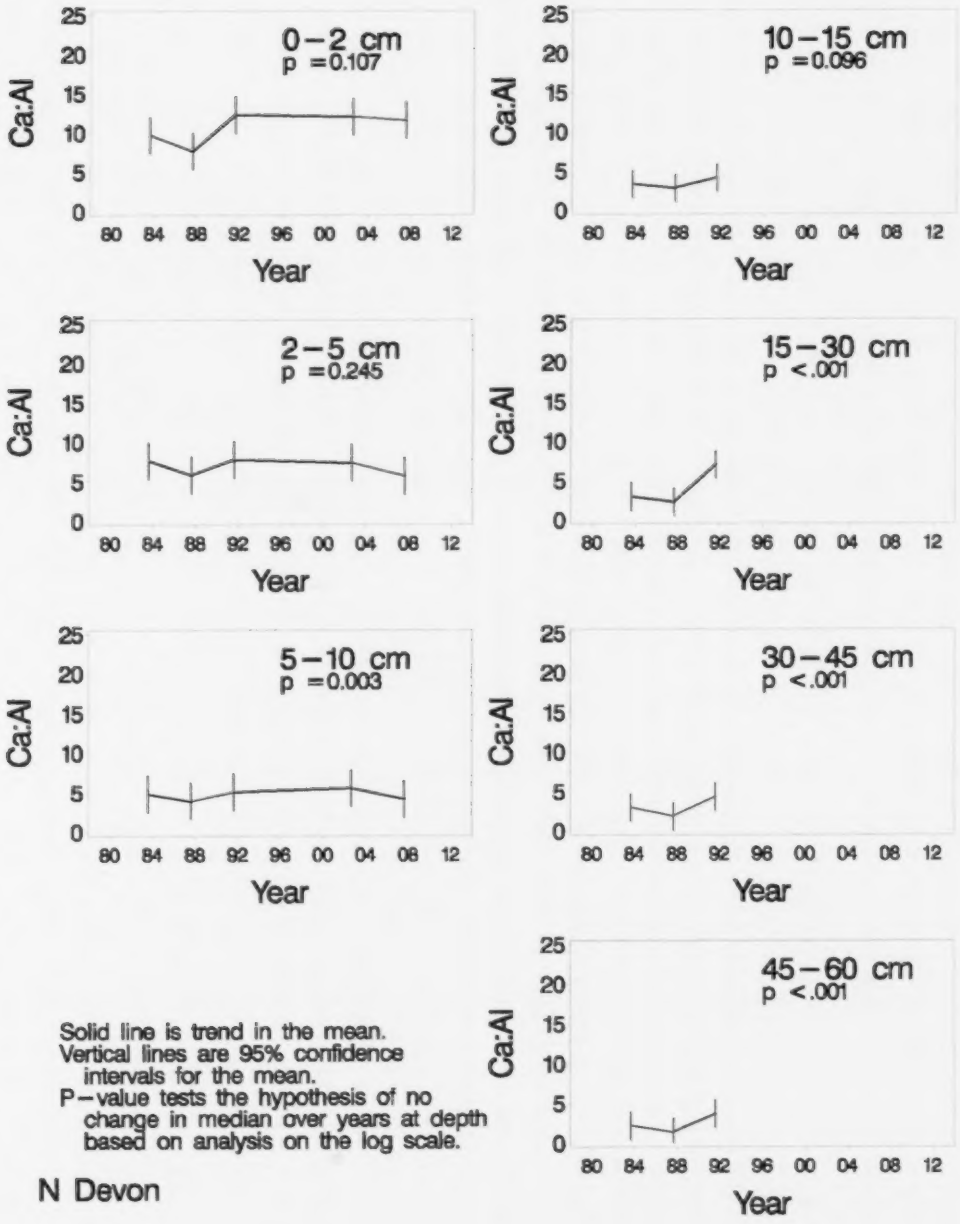






Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on the log scale.

S Fort Saskatchewan



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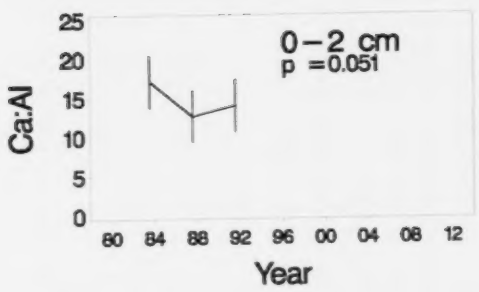
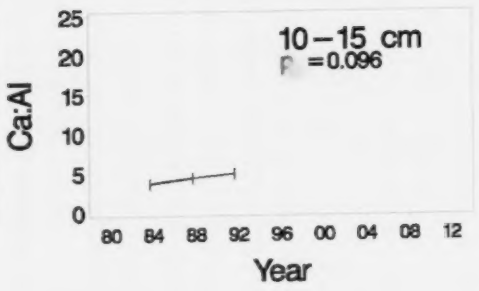
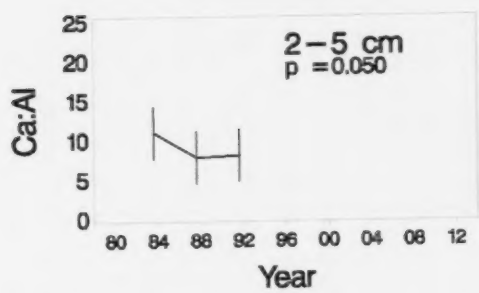
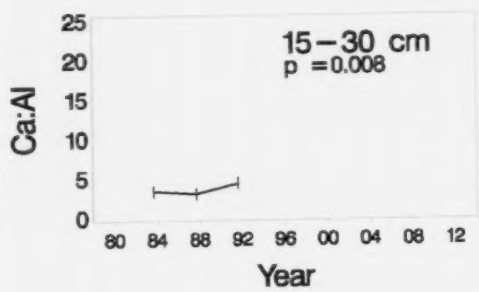
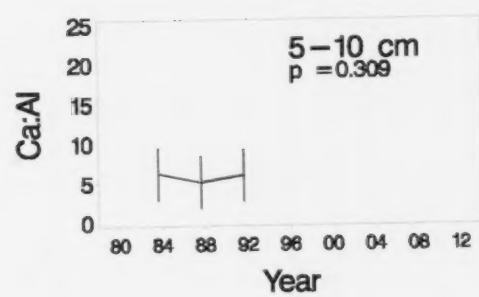
N Devon

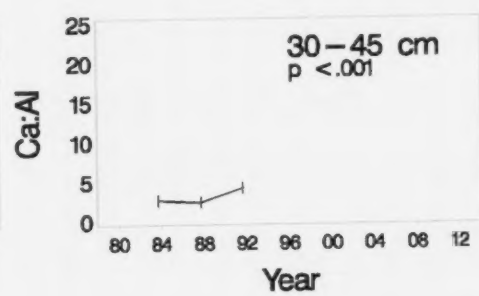


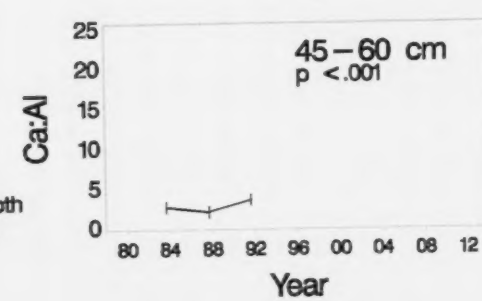












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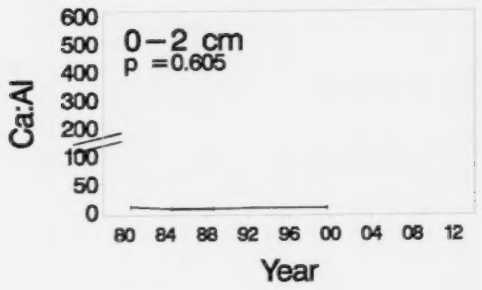
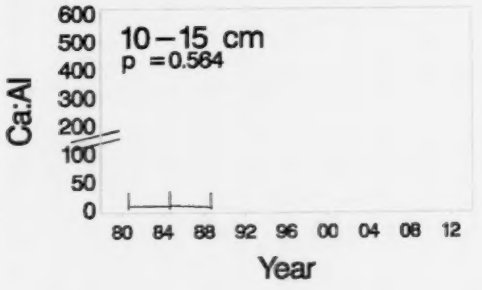
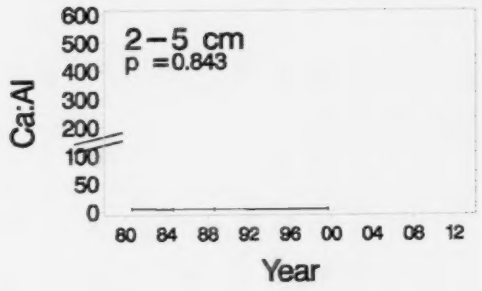
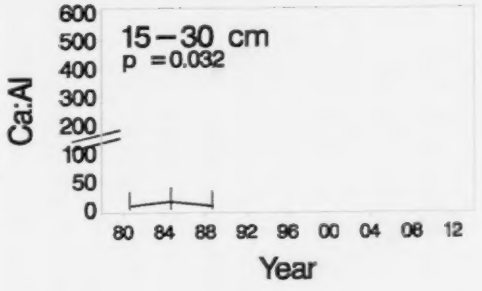
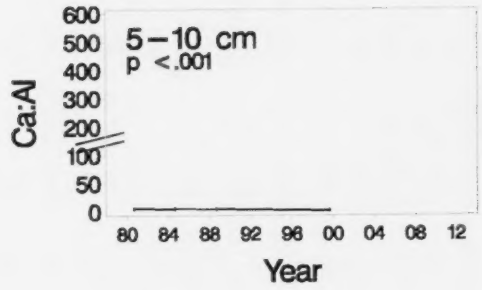
S Devon

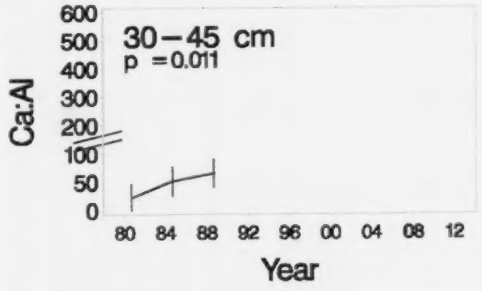


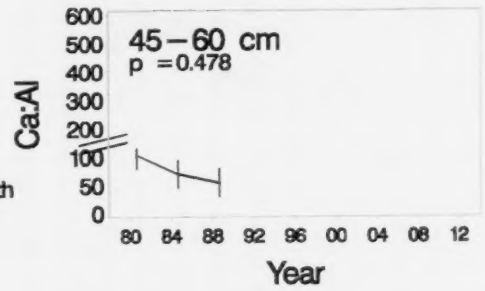












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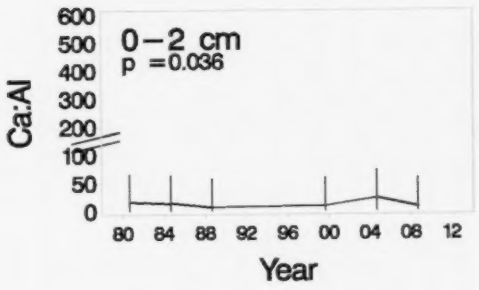
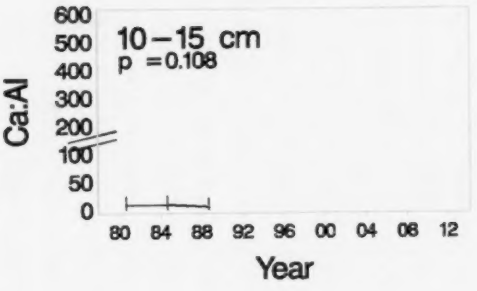
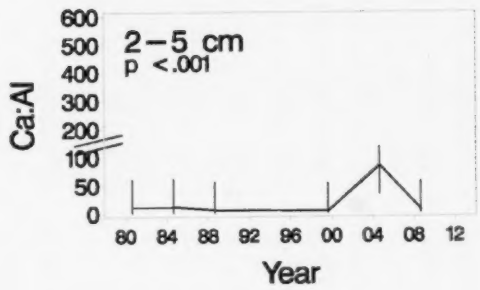
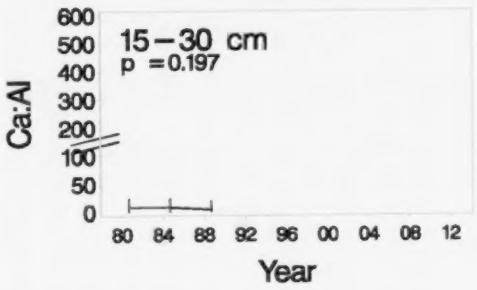
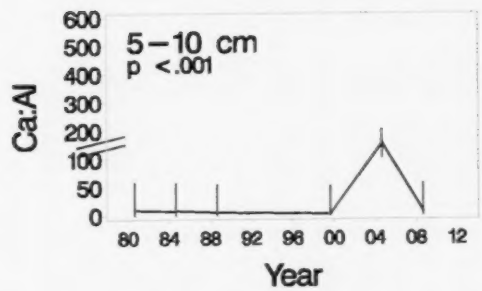
N Rocky Mountain House

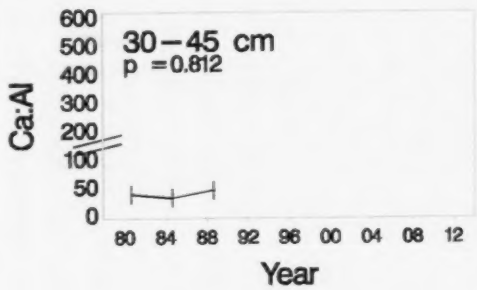


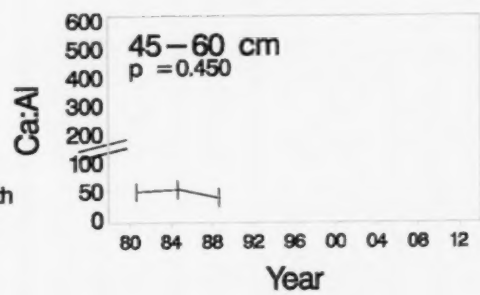












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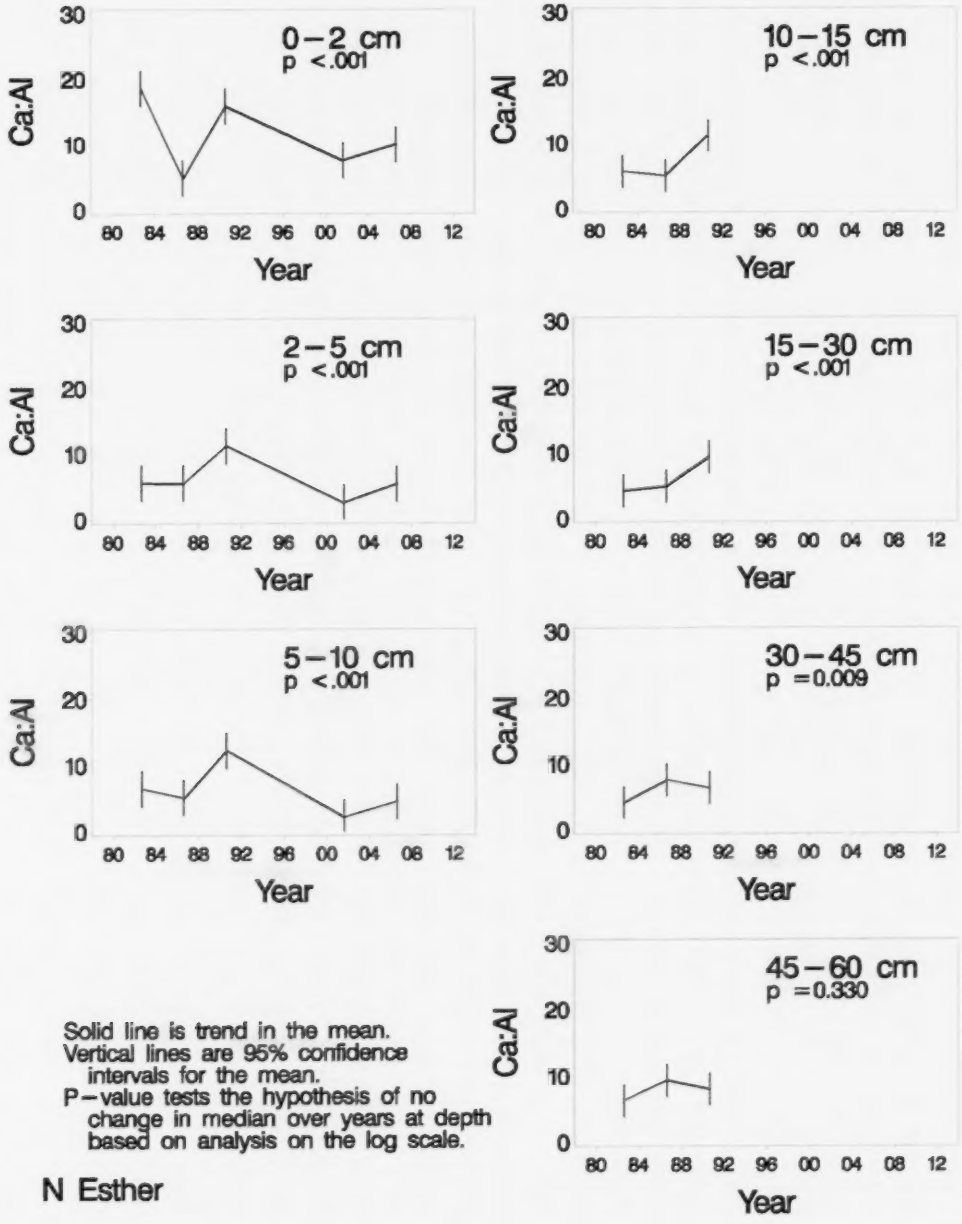
S Rocky Mountain House



Solid line is trend in the mean.
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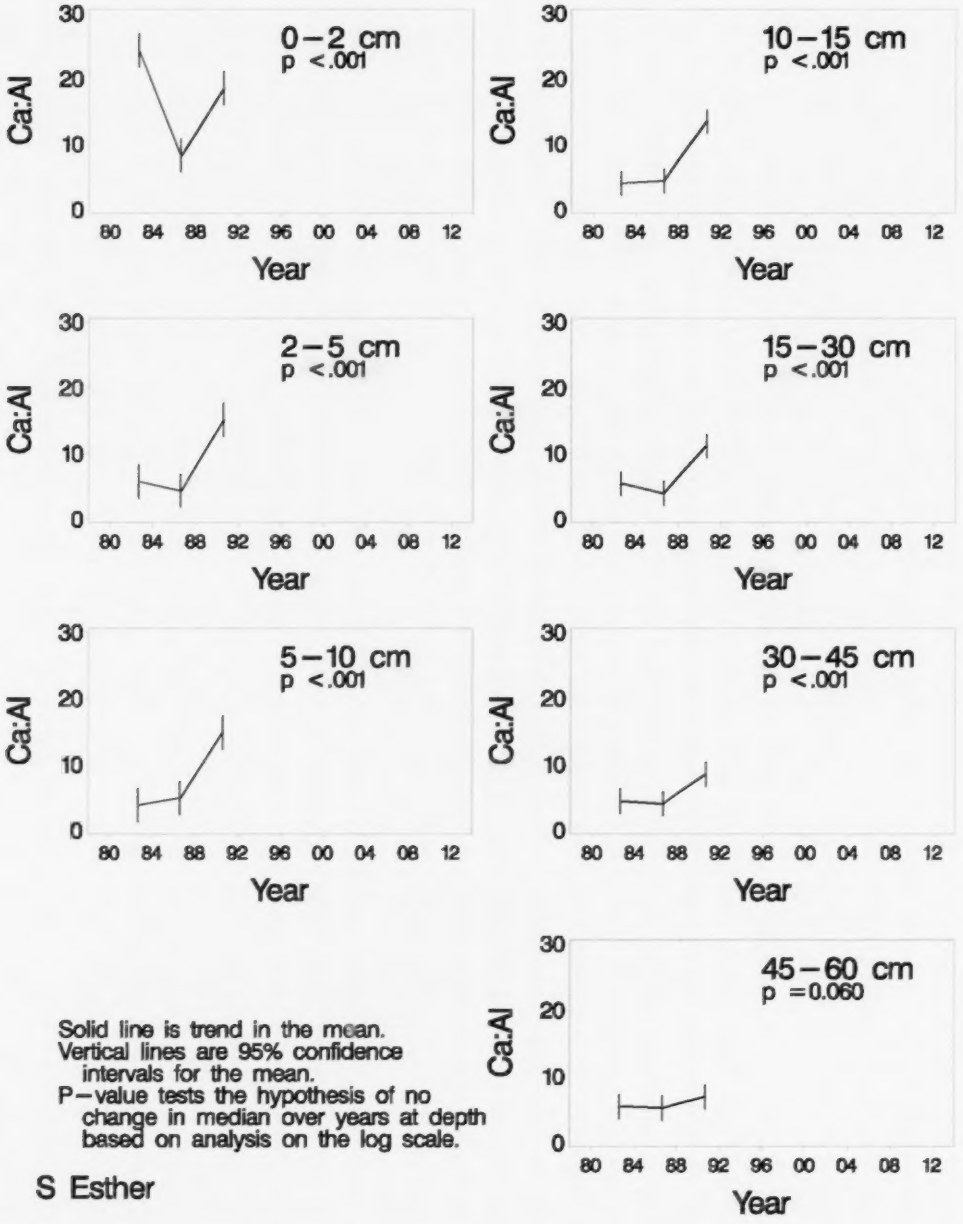
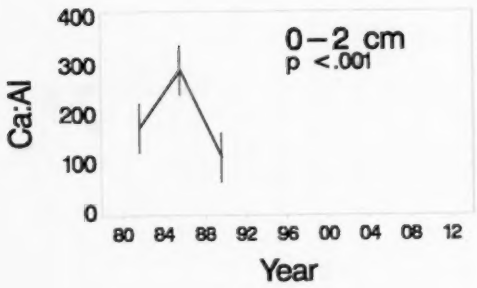
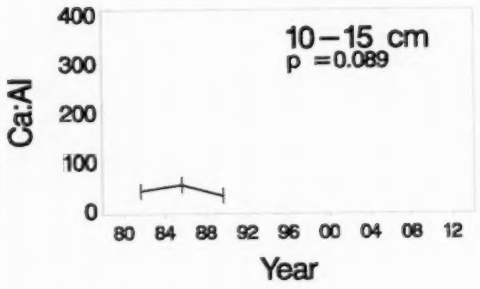
N Esther

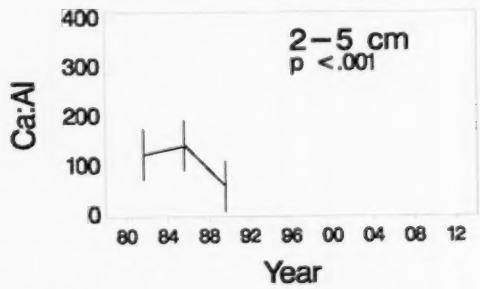


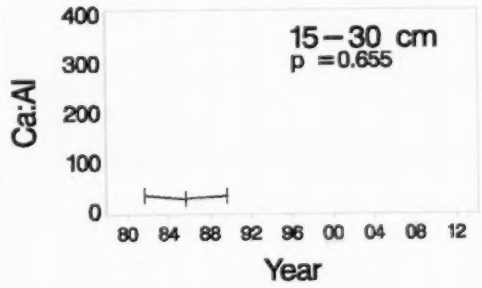
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on the log scale.

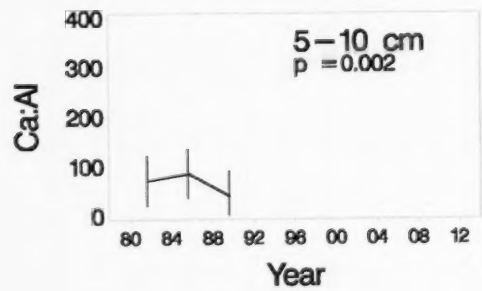
S Esther

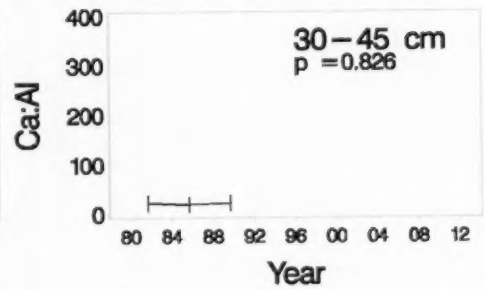


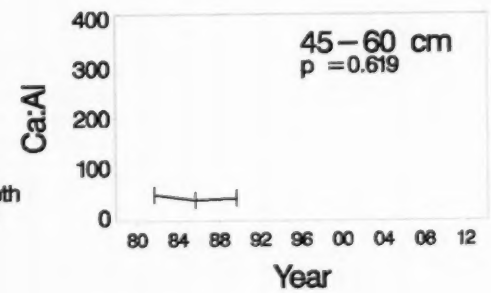












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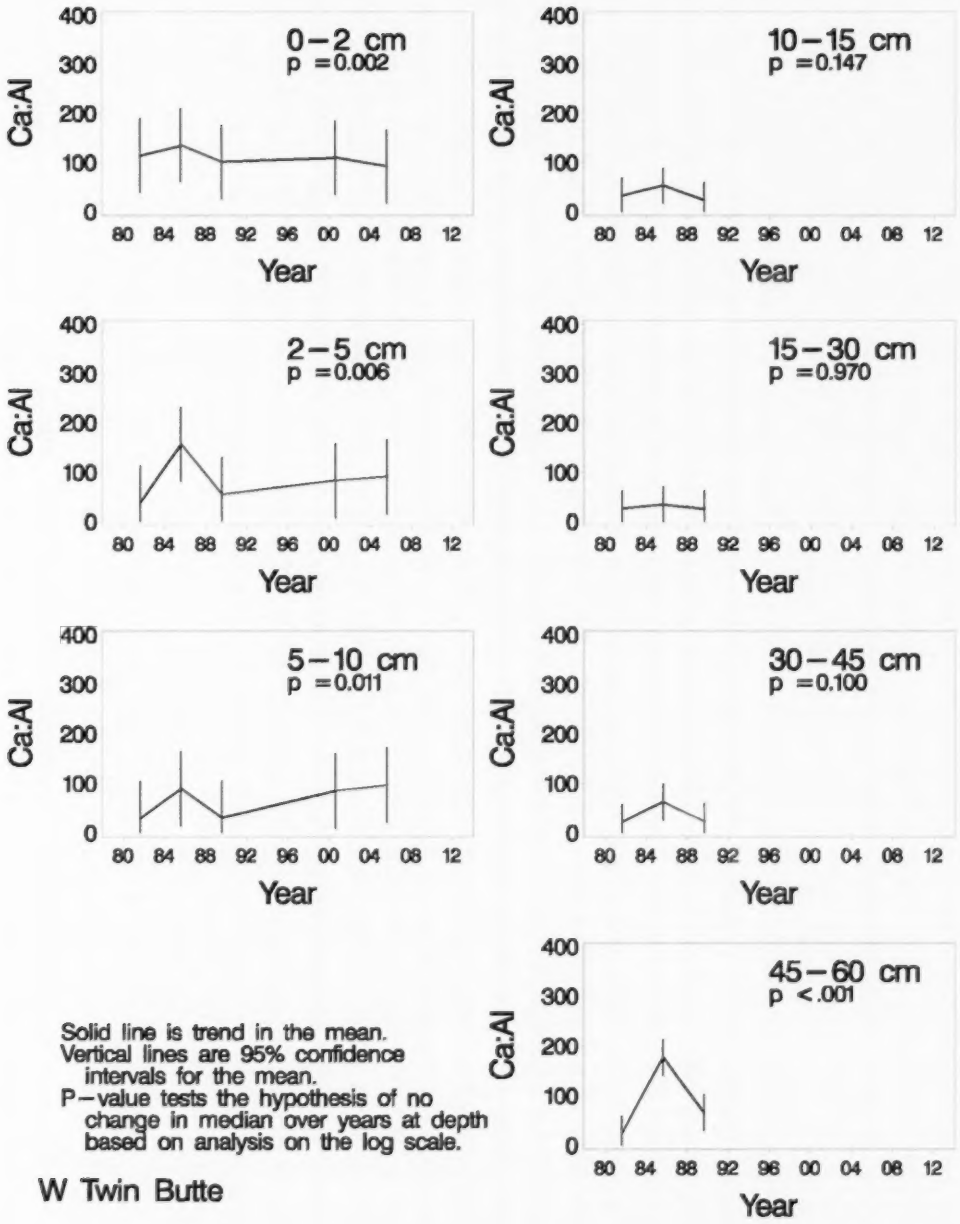
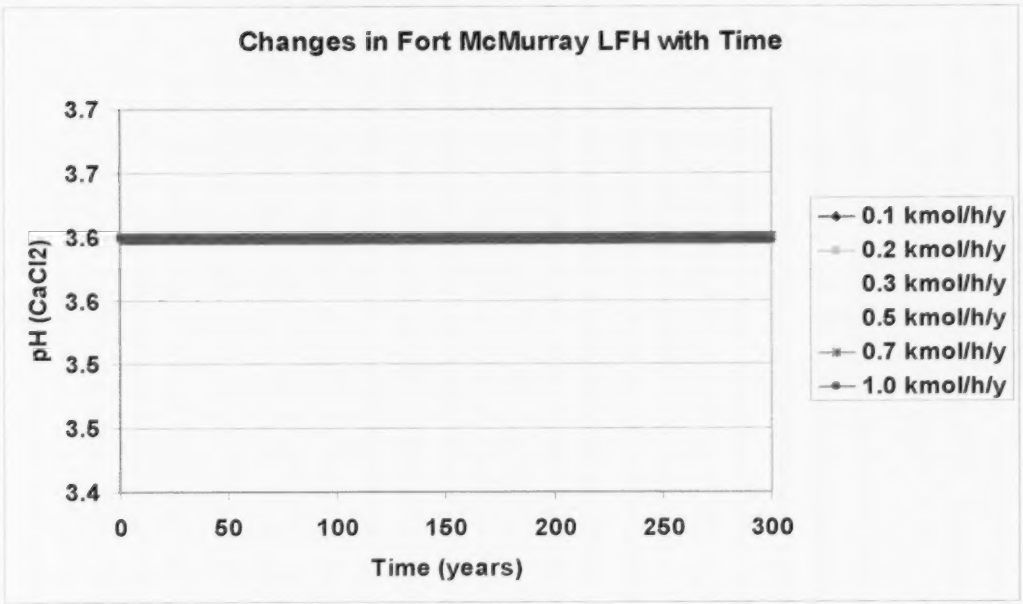
E Twin Butte

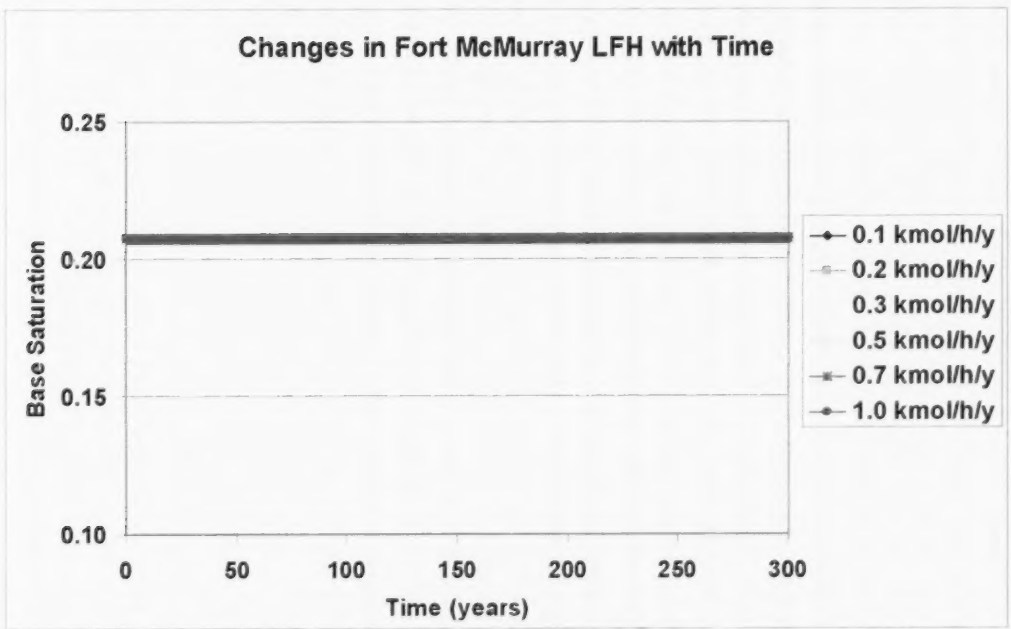

0–2 cm
p =0.002
10–15 cm
p =0.147
2–5 cm
p =0.006
15–30 cm
p =0.970
5–10 cm
p =0.011
30–45 cm
p =0.100
45–60 cm
p <.001
Ca:Al
Year
400
300
200
100
0
80 84 88 92 96 00 04 08 12
Solid line is trend in the mean.
Vertical lines are 95% confidence intervals for the mean.
P–value tests the hypothesis of no change in median over years at depth based on analysis on the log scale.
W Twin Butte

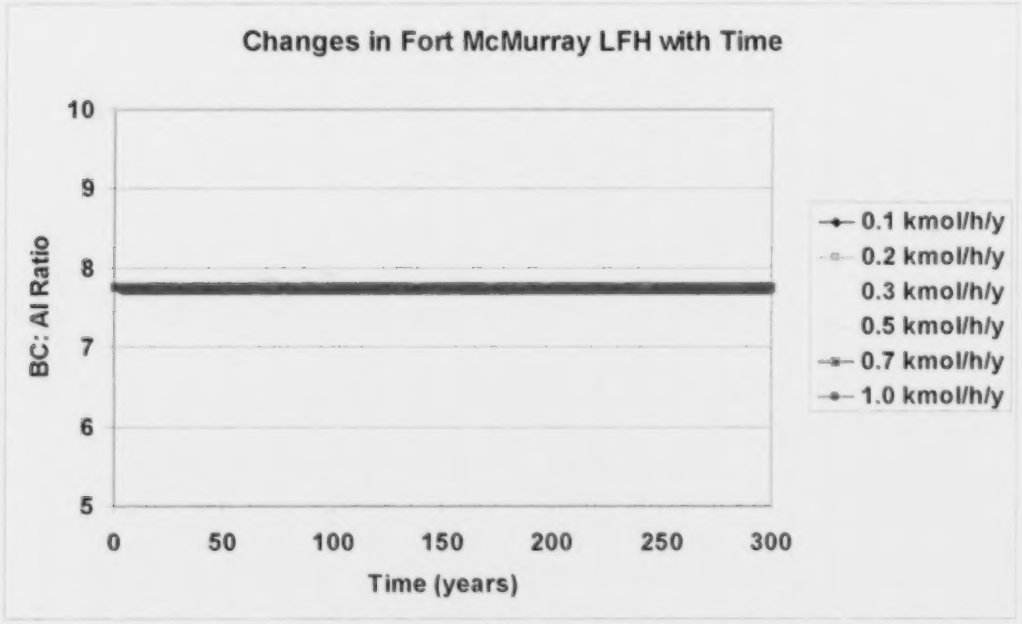
APPENDIX D

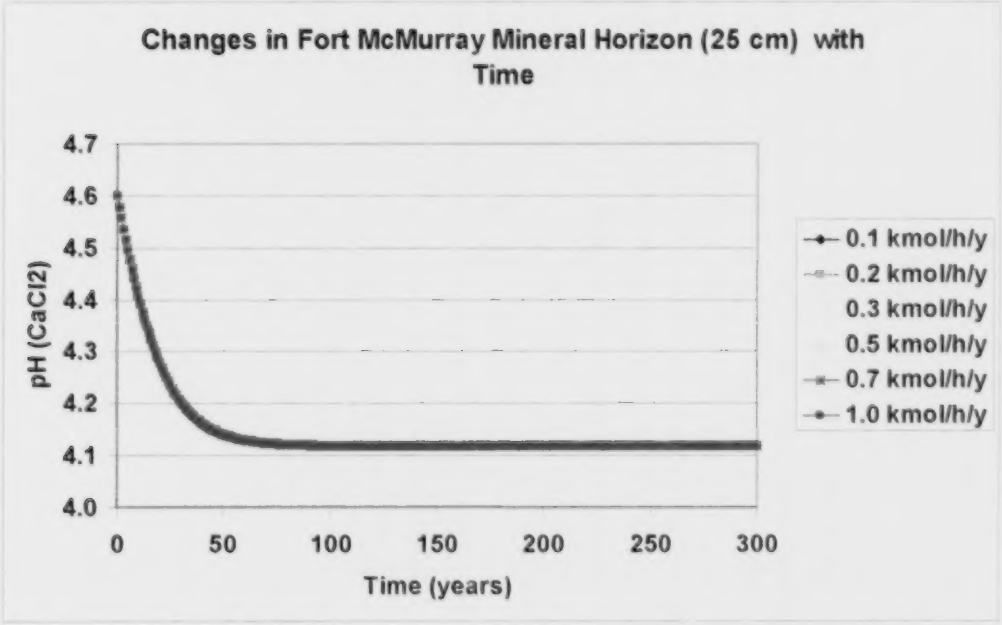
ARC MODEL SIMULATIONS OF LONG TERM SAMPLING PLOT SOIL pH, BASE SATURATION AND BASE CATION:ALUMINUM (BC:AL) RATIO IN RESPONSE TO VARIOUS ACID LOADINGS

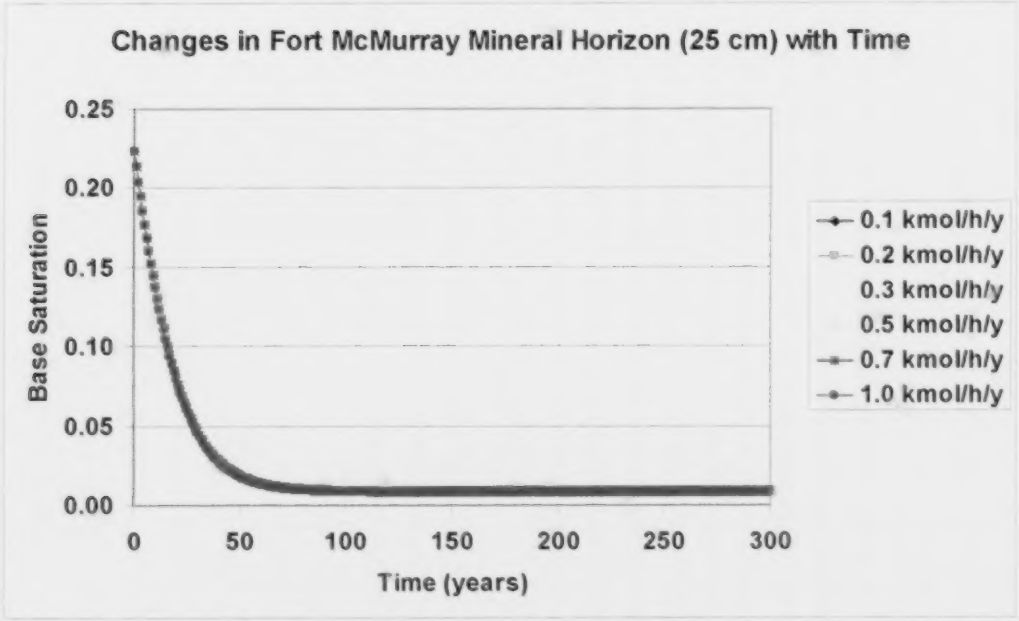
Insert Graphs

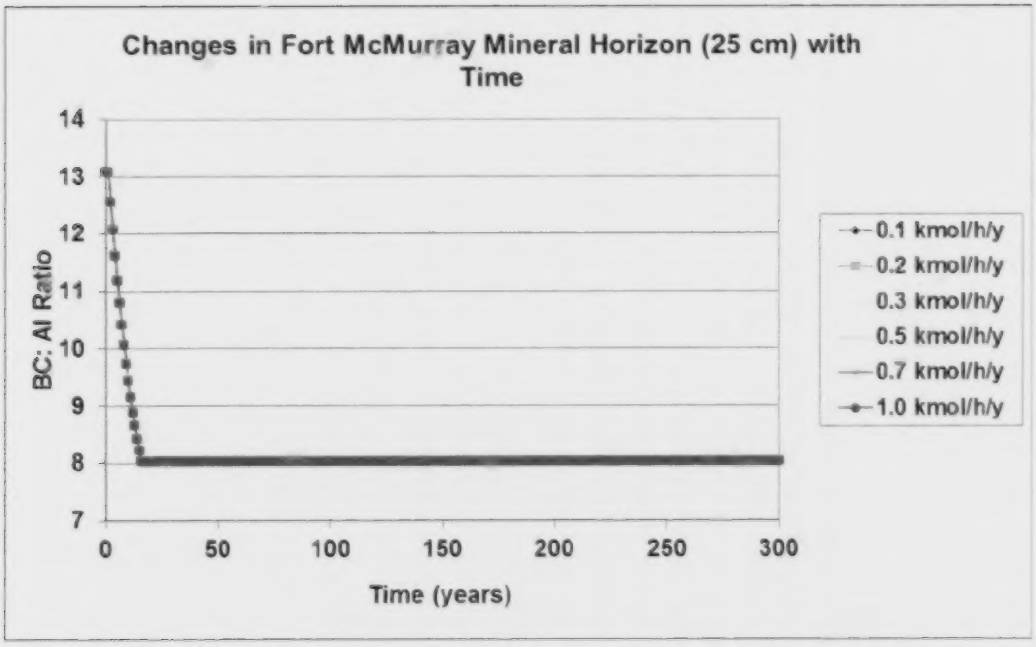


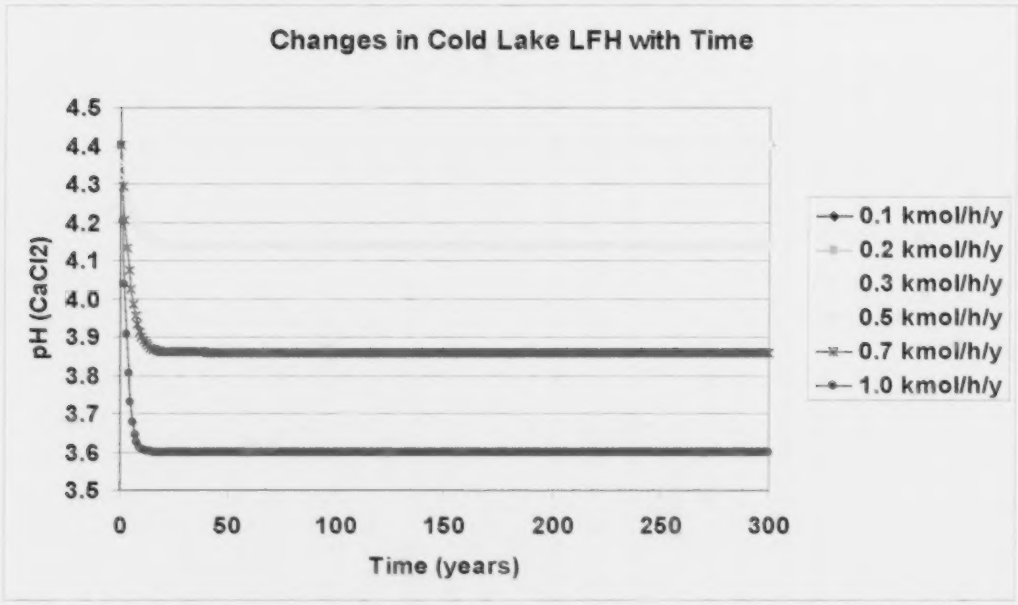


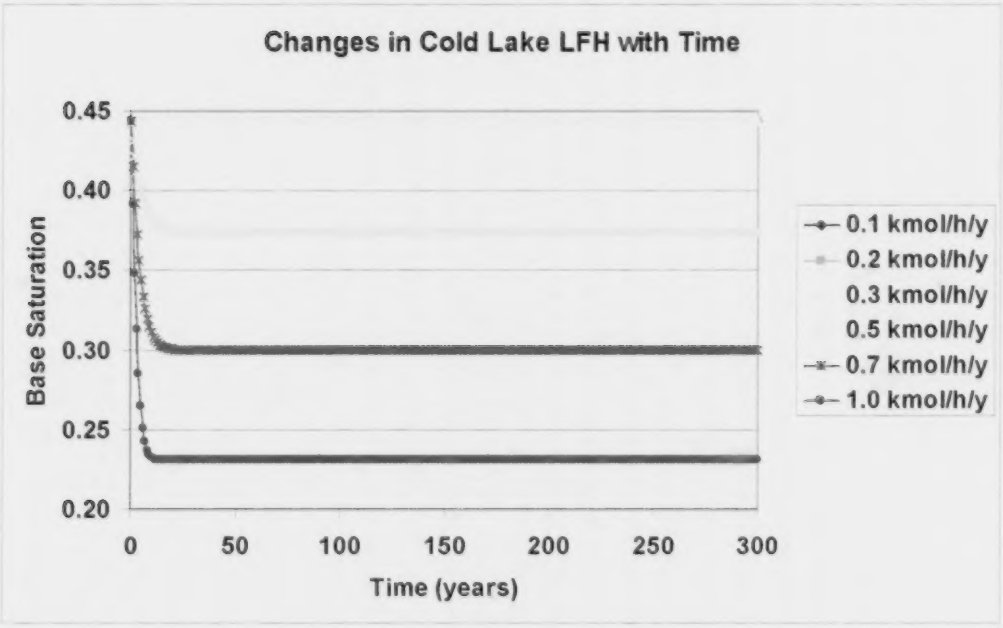

Changes in Fort McMurray LFH with Time
BC: Al Ratio
10
9
8
7
6
5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

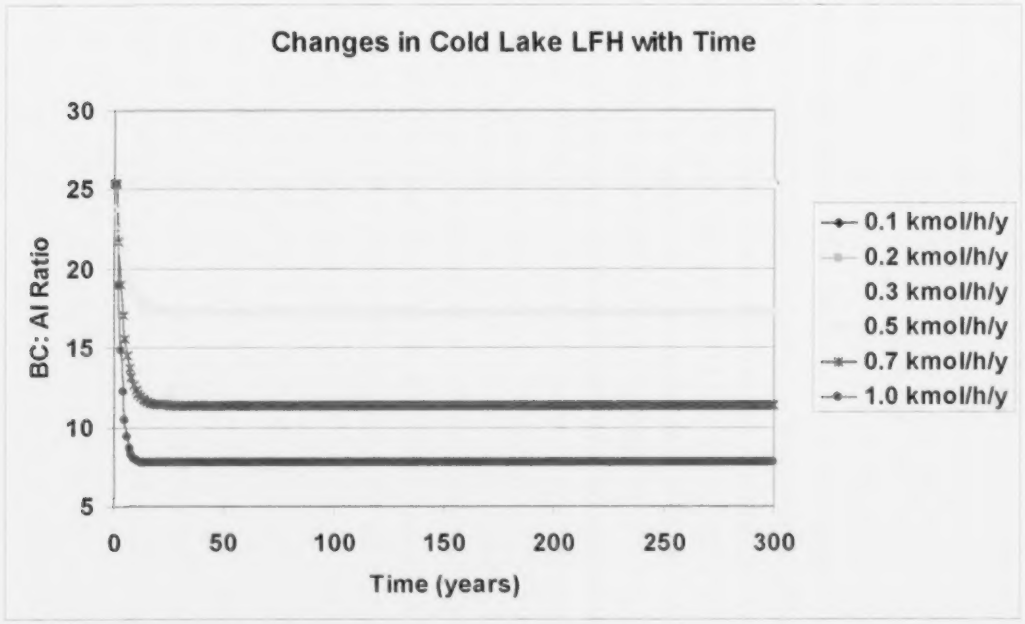

Changes in Fort McMurray Mineral Horizon (25 cm) with Time
pH (CaCl2)
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

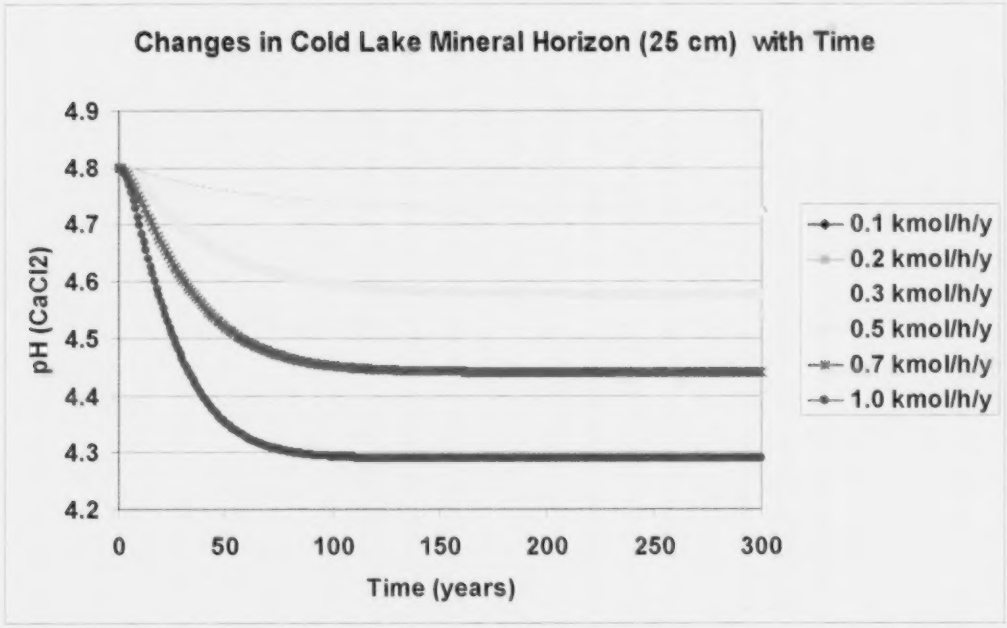

Changes in Fort McMurray Mineral Horizon (25 cm) with Time
Base Saturation
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

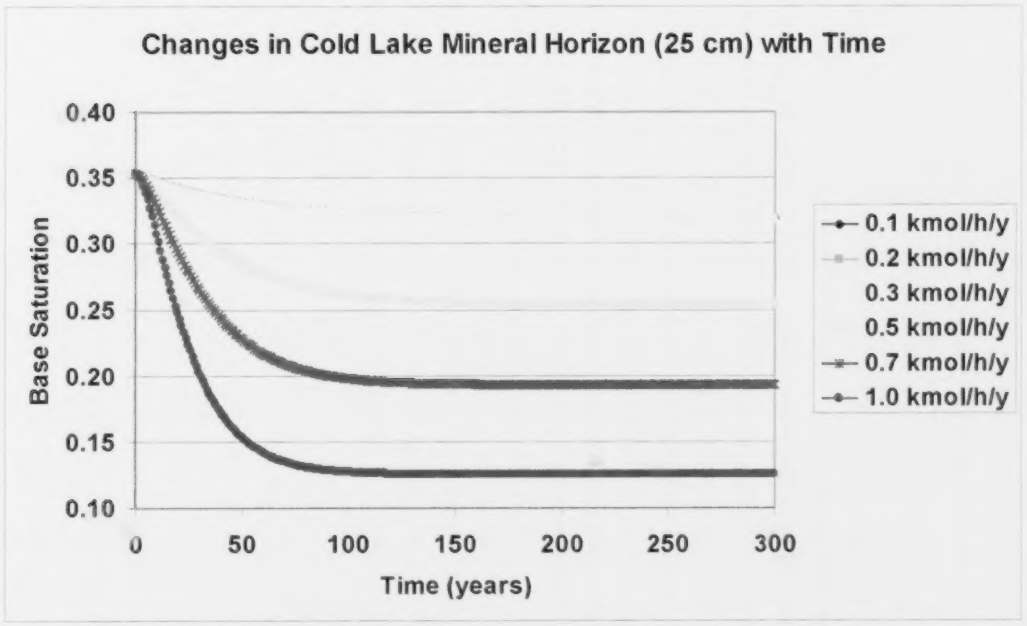

Changes in Fort McMurray Mineral Horizon (25 cm) with Time
BC: Al Ratio
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

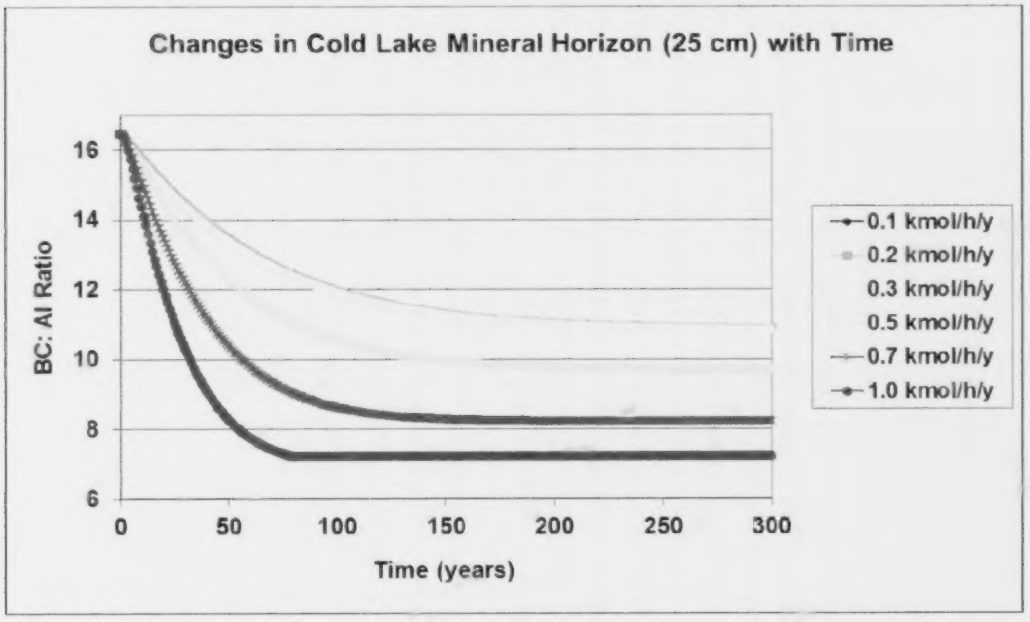

Changes in Cold Lake LFH with Time
pH (CaCl2)
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

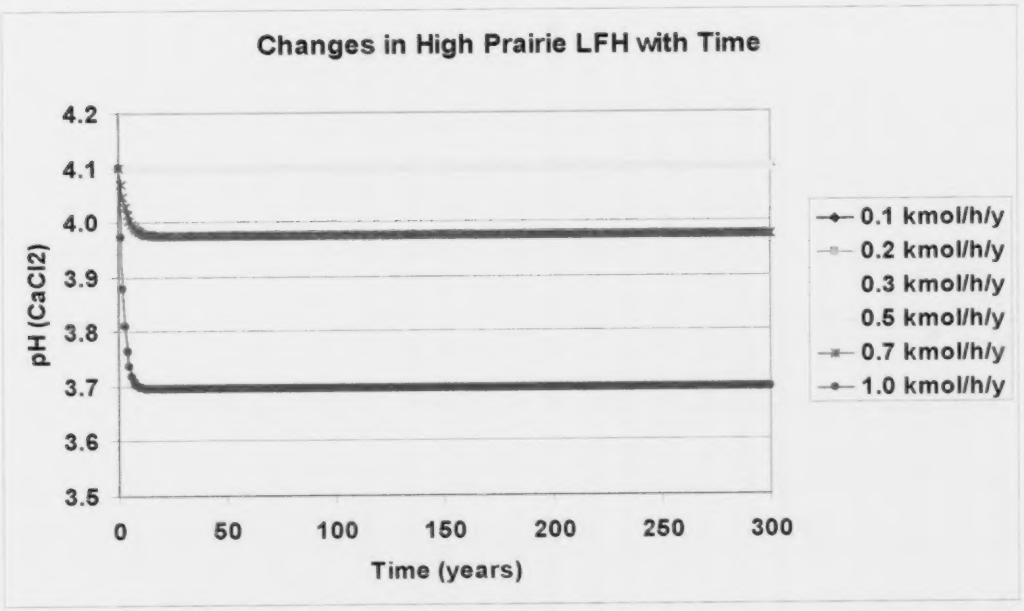

Changes in Cold Lake LFH with Time
Base Saturation
0.45
0.40
0.35
0.30
0.25
0.20
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

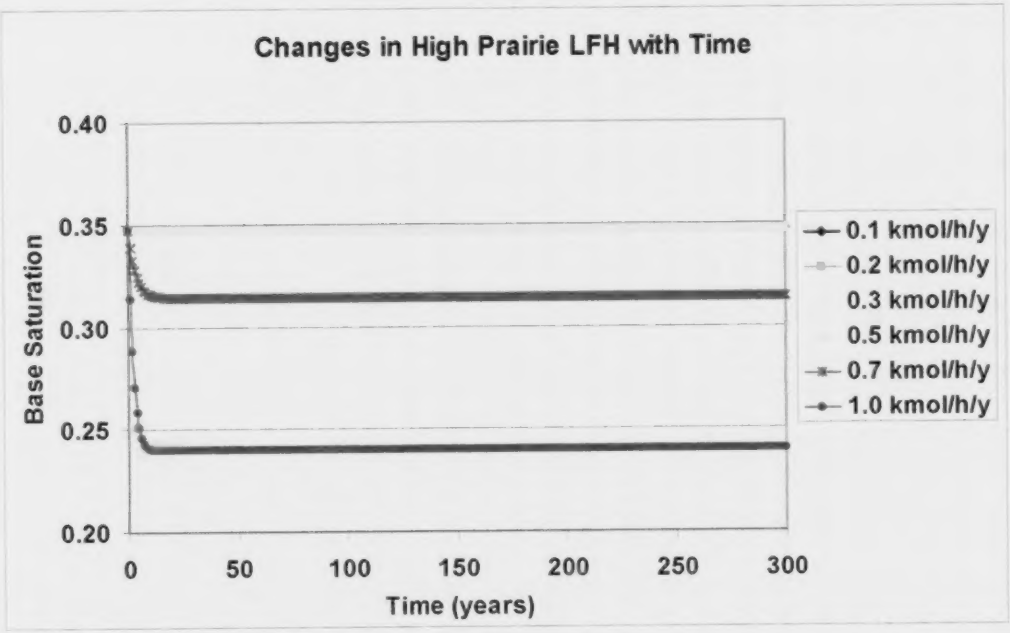

Changes in Cold Lake LFH with Time
BC: Al Ratio
30
25
20
15
10
5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

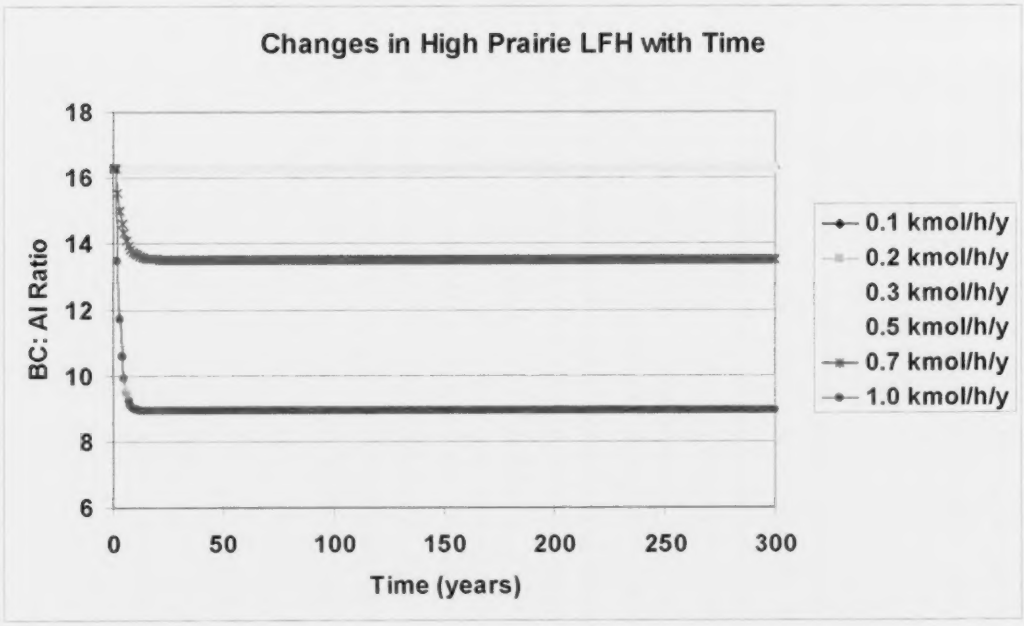

Changes in Cold Lake Mineral Horizon (25 cm) with Time
pH (CaCl2)
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

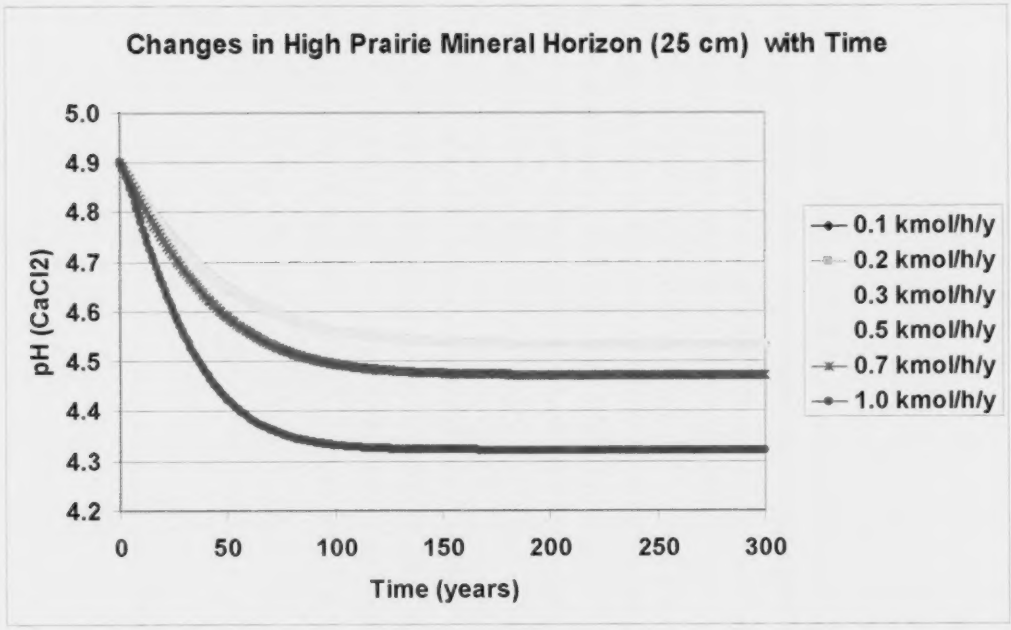

Changes in Cold Lake Mineral Horizon (25 cm) with Time
Base Saturation
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

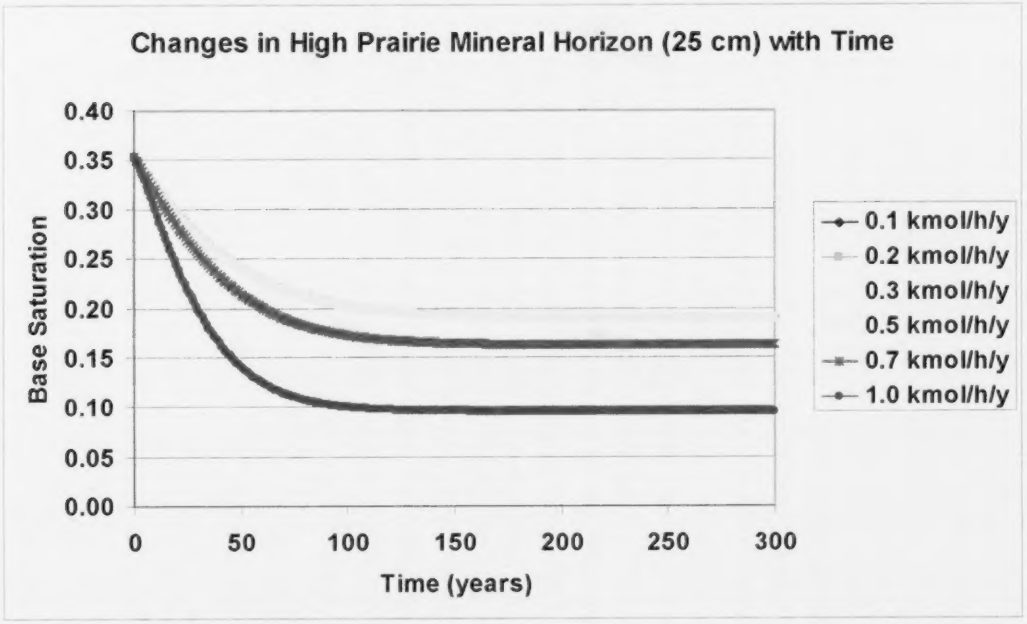

Changes in Cold Lake Mineral Horizon (25 cm) with Time
BC: Al Ratio
16
14
12
10
8
6
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

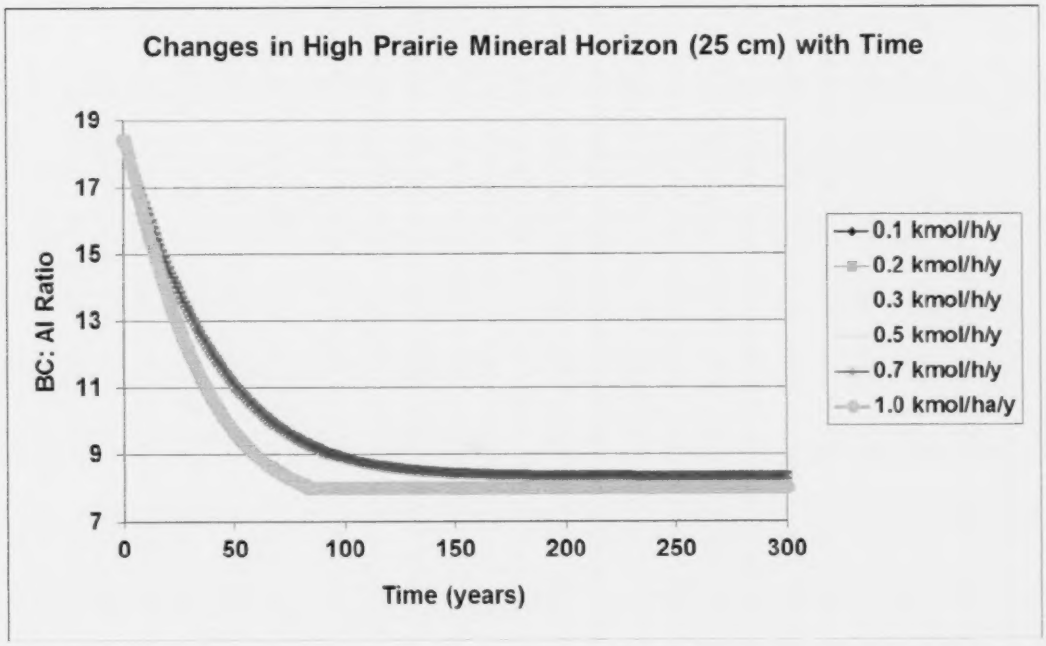

Changes in High Prairie LFH with Time
pH (CaCl2)
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

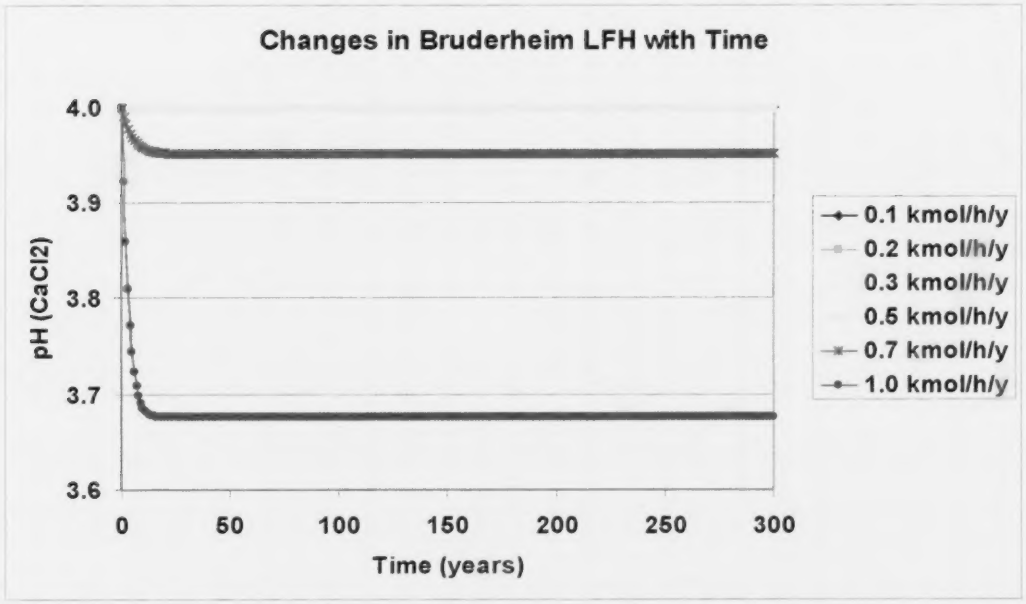

Changes in High Prairie LFH with Time
Base Saturation
0.40
0.35
0.30
0.25
0.20
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

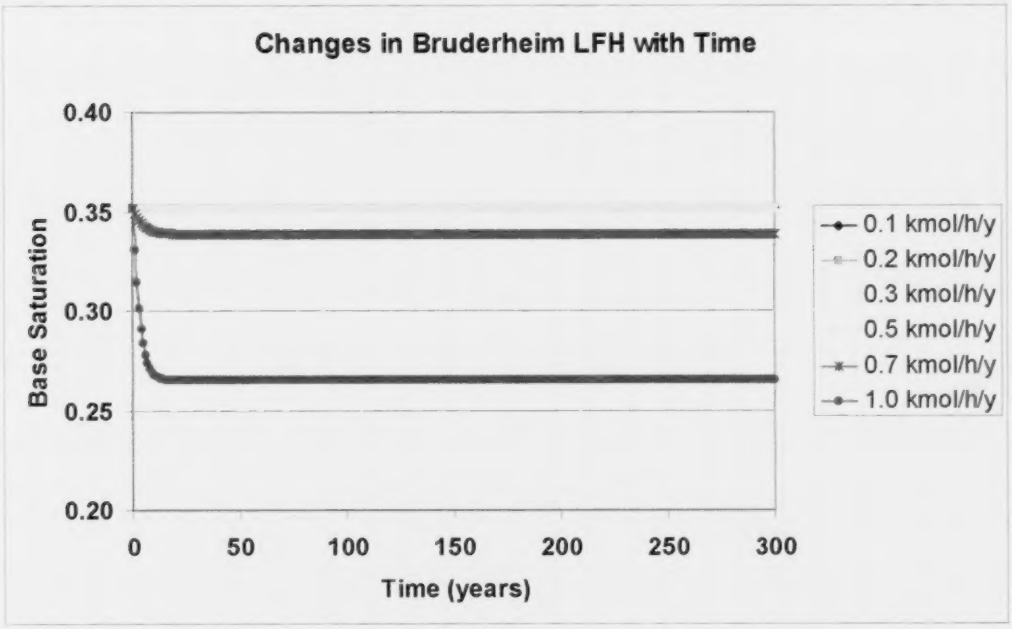

Changes in High Prairie LFH with Time
BC: Al Ratio
18
16
14
12
10
8
6
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

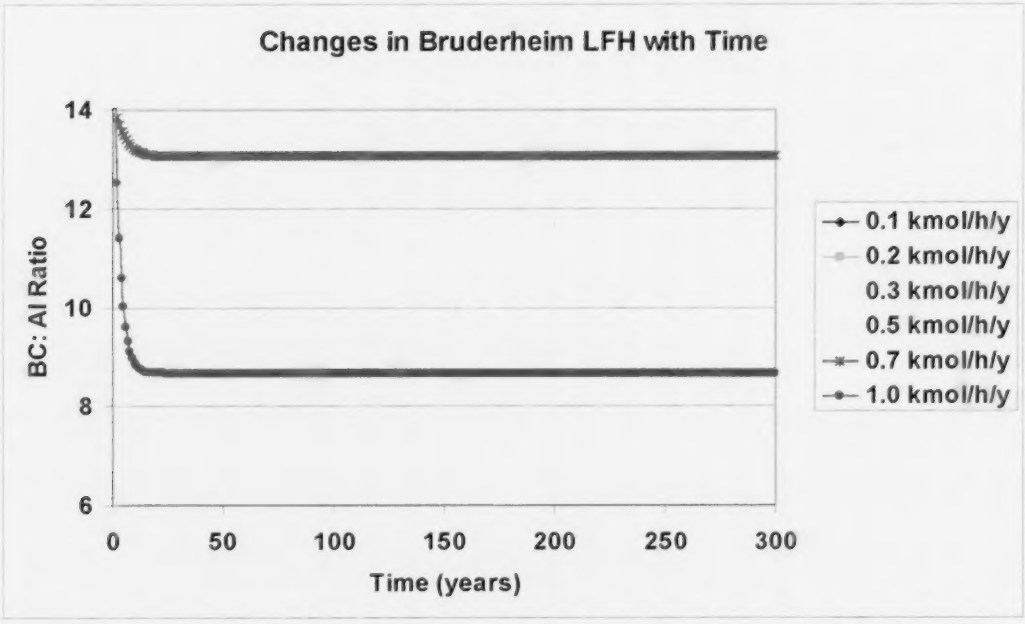

Changes in High Prairie Mineral Horizon (25 cm) with Time
pH (CaCl2)
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

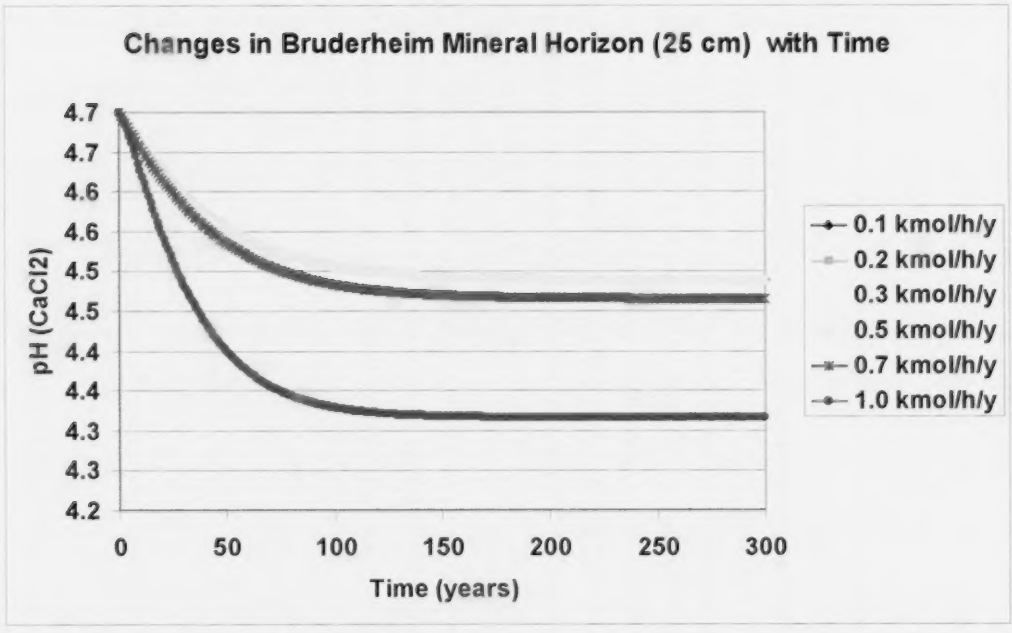

Changes in High Prairie Mineral Horizon (25 cm) with Time
Base Saturation
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

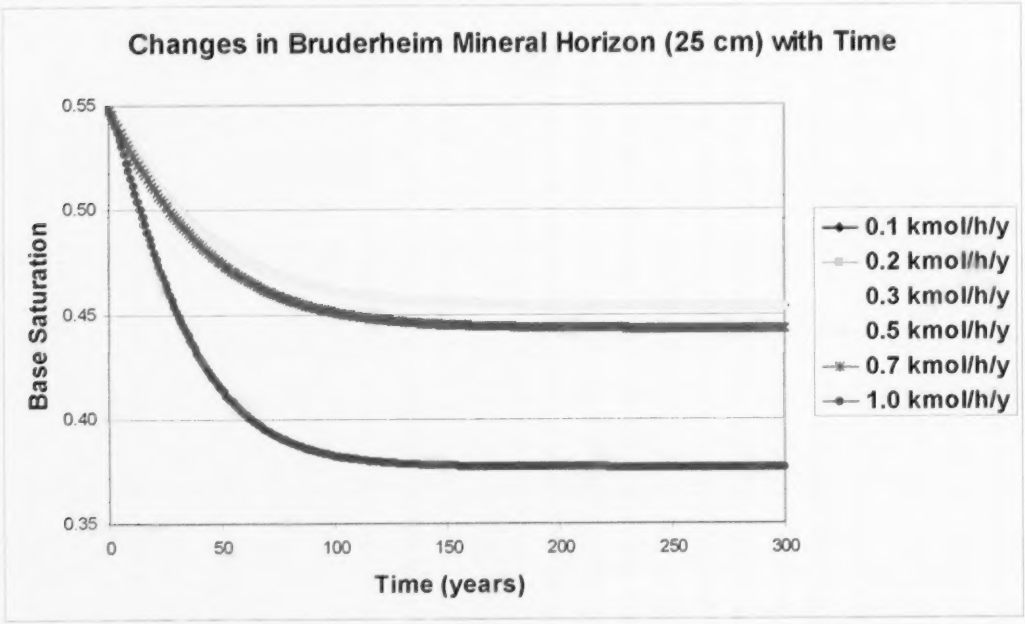

Changes in High Prairie Mineral Horizon (25 cm) with Time
BC: Al Ratio
19
17
15
13
11
9
7
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/ha/y

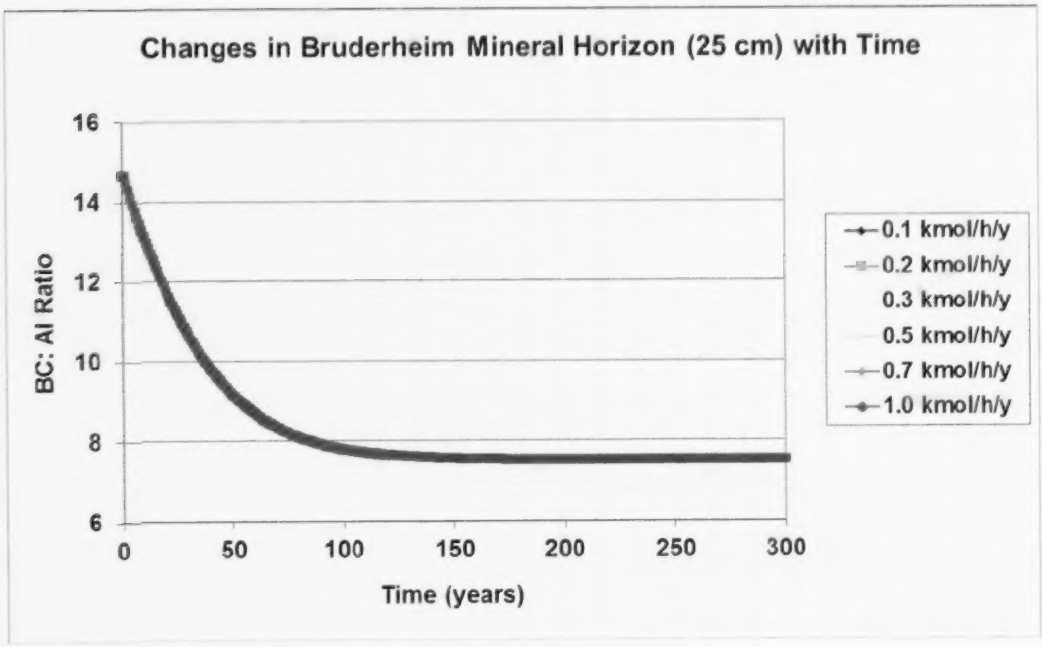

Changes in Bruderheim LFH with Time
4.0
3.9
3.8
3.7
3.6
pH (CaCl2)
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

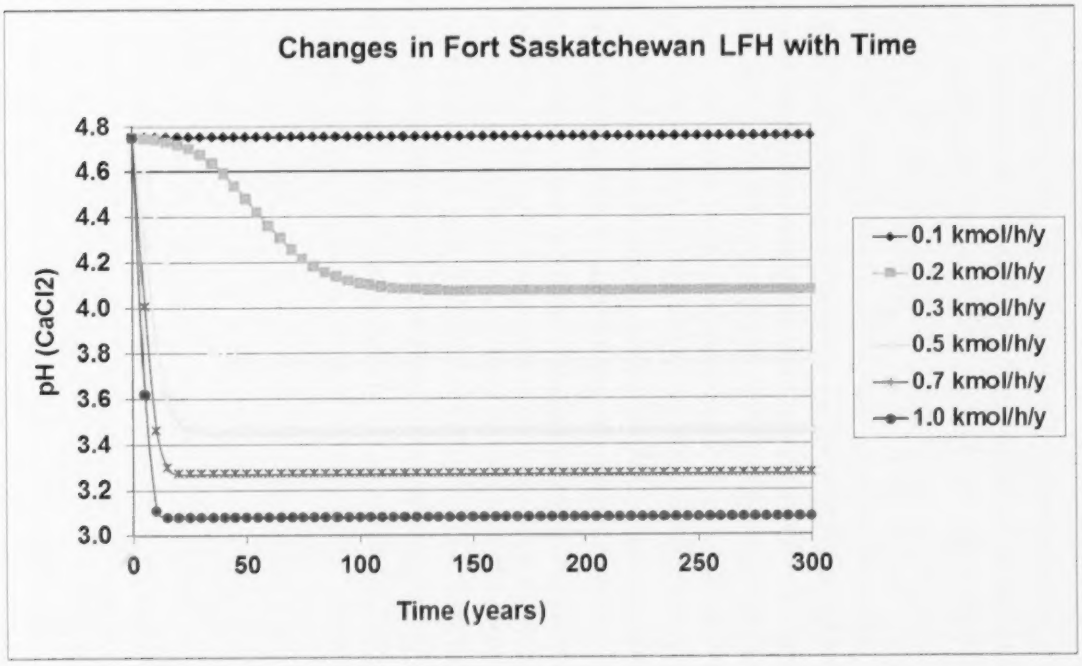

Changes in Bruderheim LFH with Time
0.40
0.35
0.30
0.25
0.20
Base Saturation
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

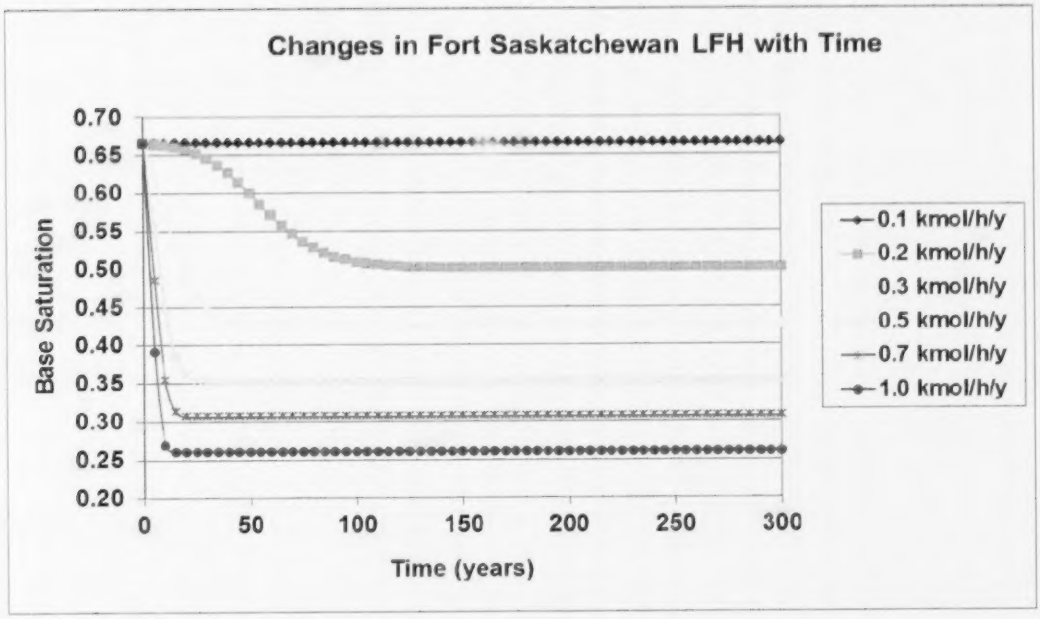

Changes in Bruderheim LFH with Time
BC: Al Ratio
14
12
10
8
6
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

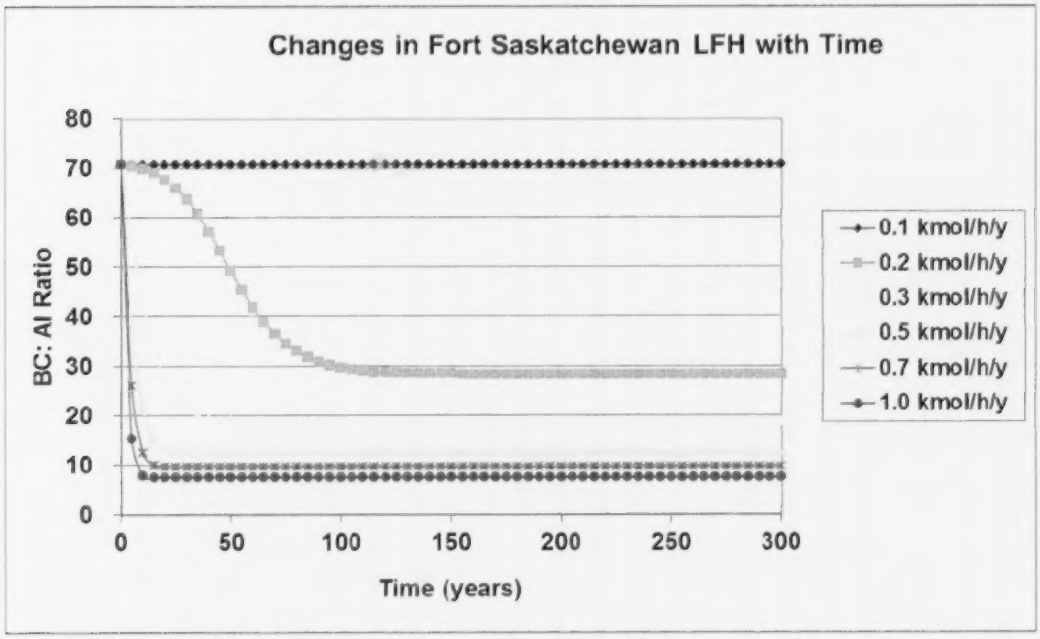

Changes in Bruderheim Mineral Horizon (25 cm) with Time
pH (CaCl2)
4.7
4.7
4.6
4.6
4.5
4.5
4.4
4.4
4.3
4.3
4.2
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

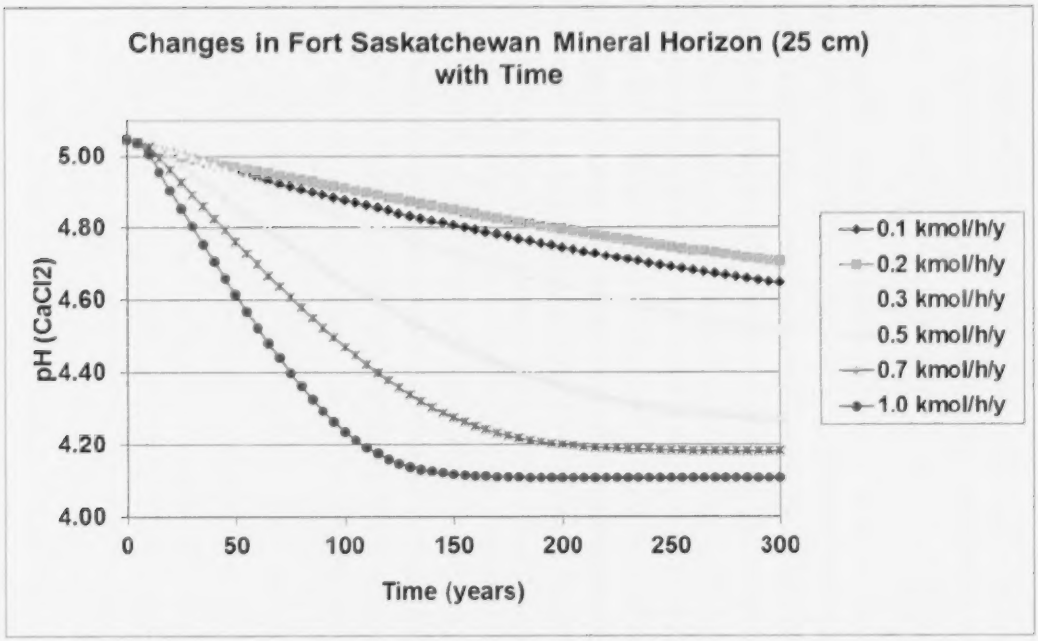

Changes in Bruderheim Mineral Horizon (25 cm) with Time
Base Saturation
0.55
0.50
0.45
0.40
0.35
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

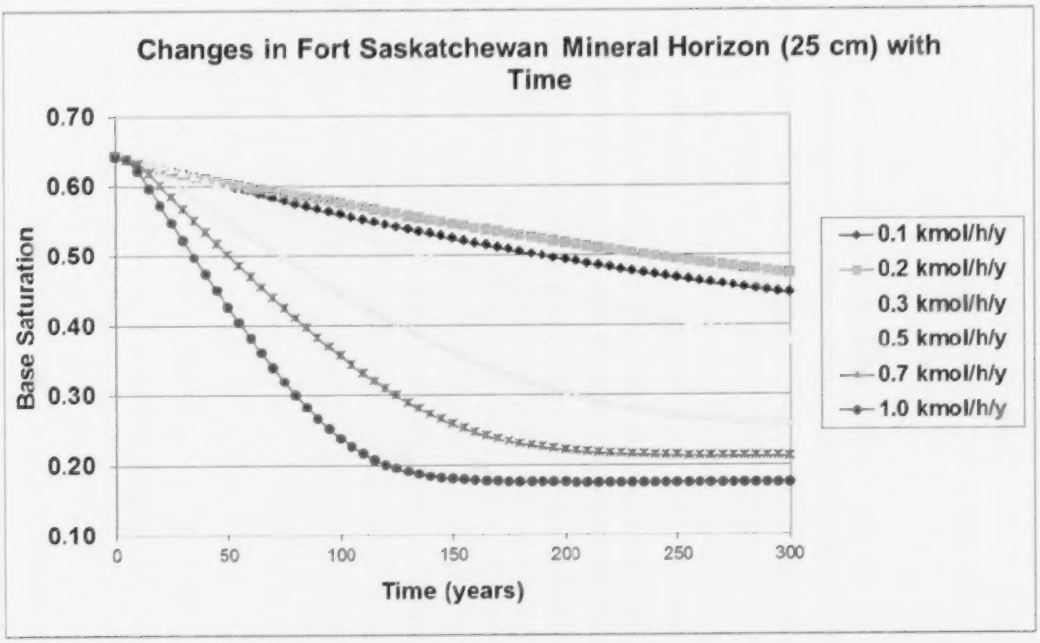

Changes in Bruderheim Mineral Horizon (25 cm) with Time
BC: Al Ratio
16
14
12
10
8
6
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

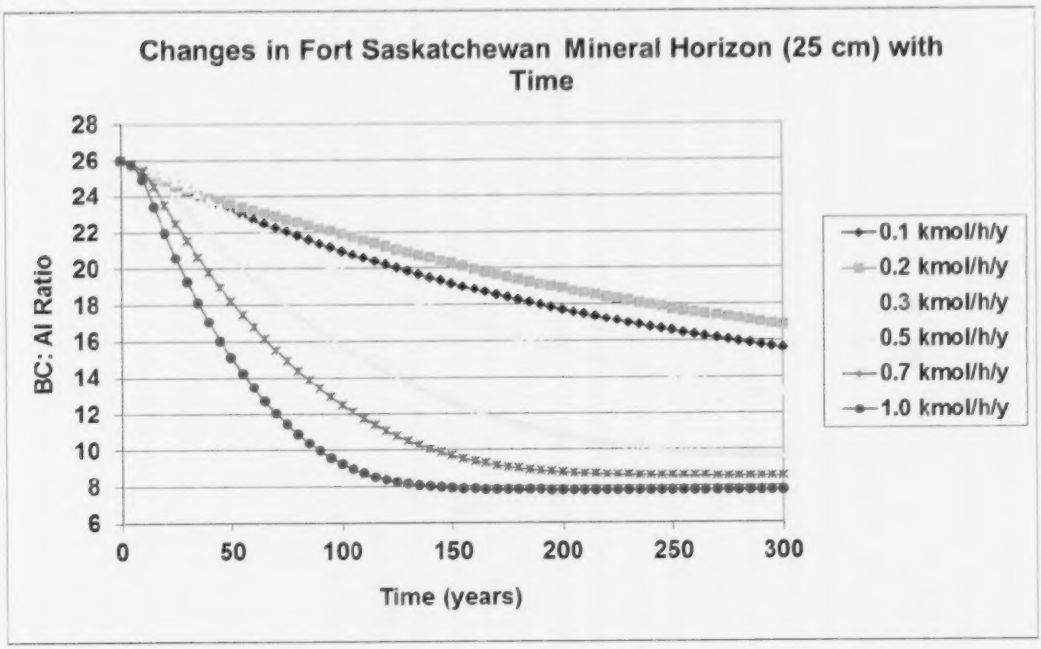

Changes in Fort Saskatchewan LFH with Time
pH (CaCl2)
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

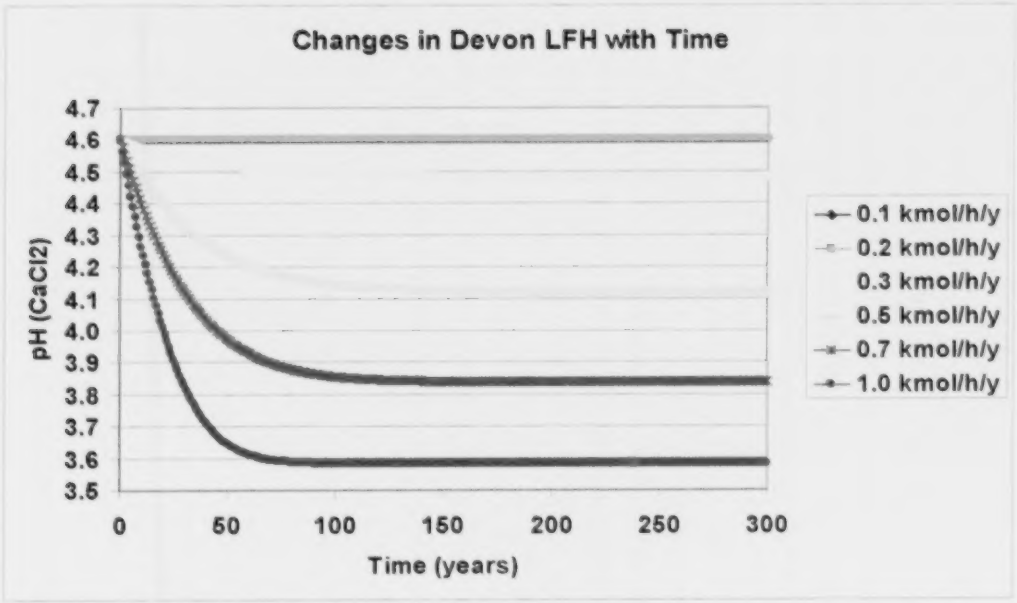

Changes in Fort Saskatchewan LFH with Time
Base Saturation
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

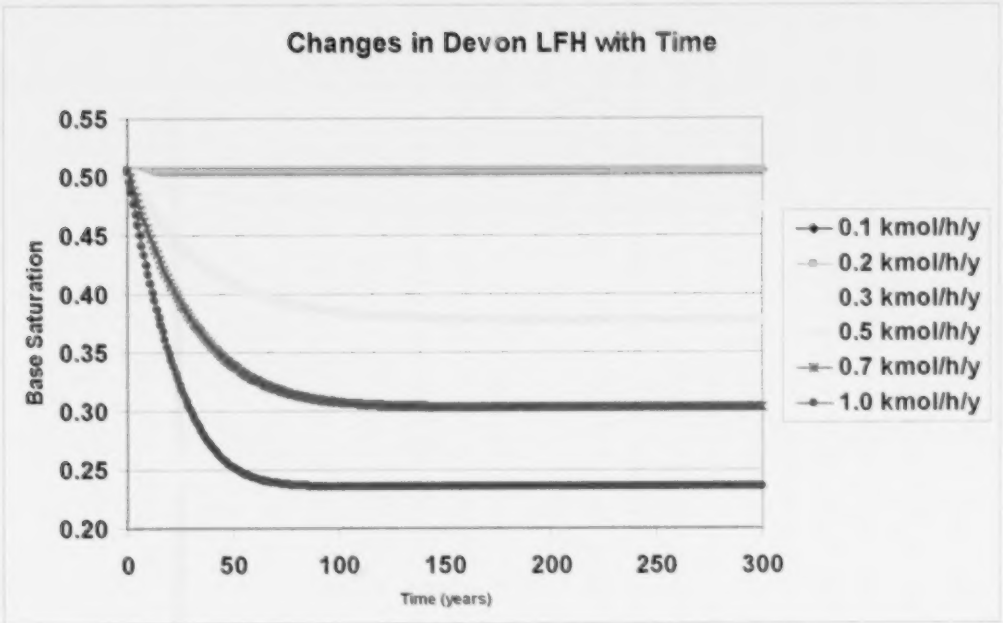

Changes in Fort Saskatchewan LFH with Time
BC: Al Ratio
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

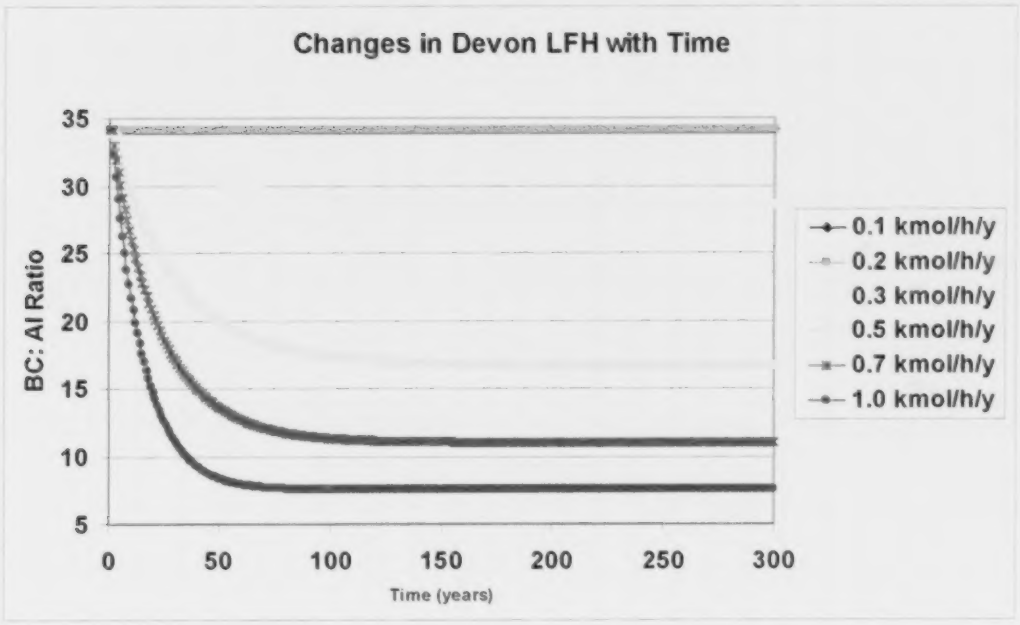

Changes in Fort Saskatchewan Mineral Horizon (25 cm) with Time
pH (CaCl2)
5.00
4.80
4.60
4.40
4.20
4.00
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

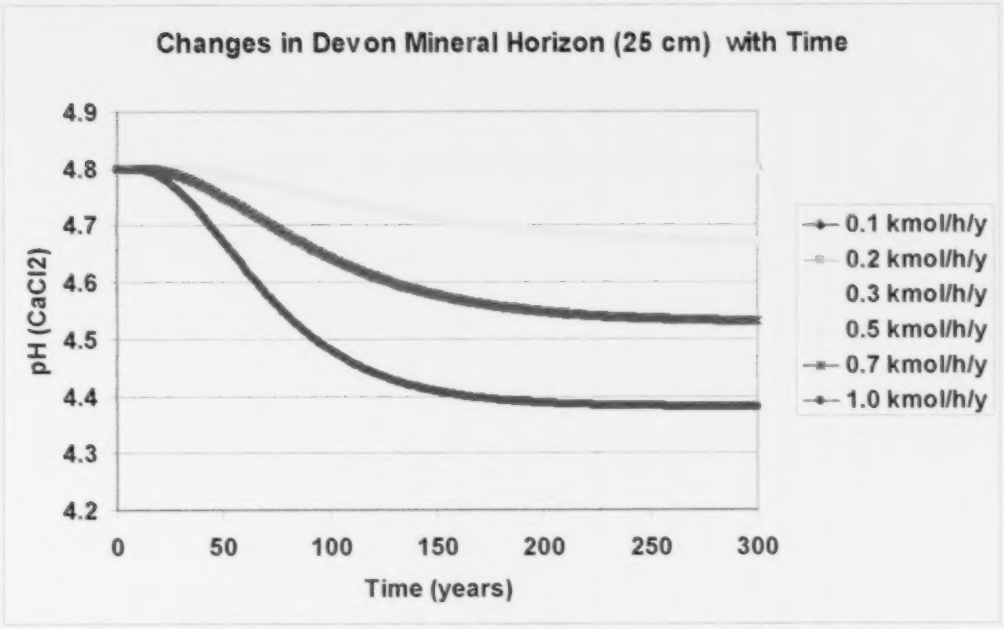

Changes in Fort Saskatchewan Mineral Horizon (25 cm) with Time
Base Saturation
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

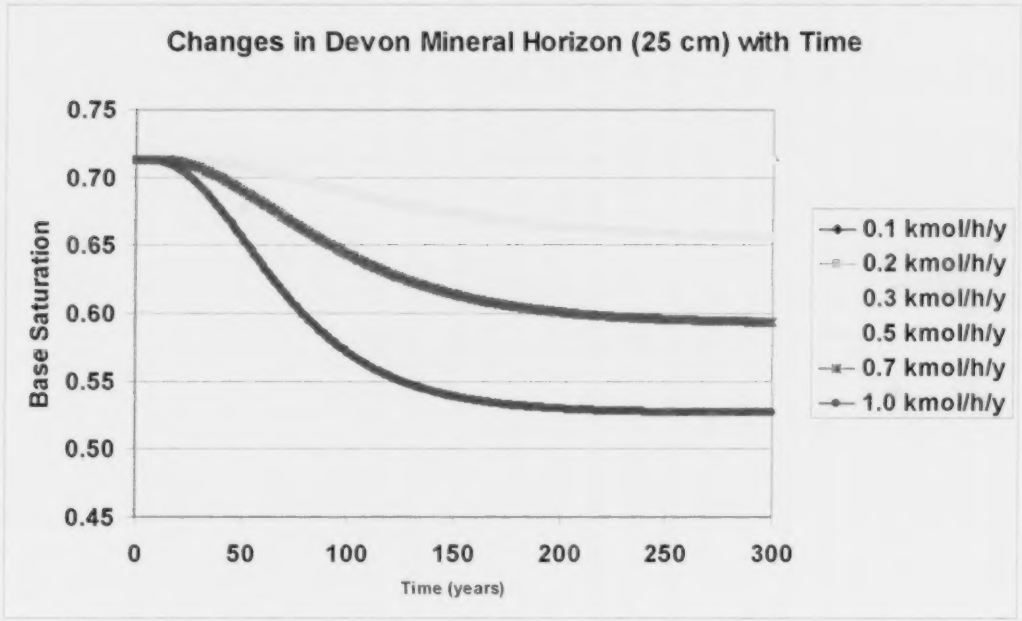

Changes in Fort Saskatchewan Mineral Horizon (25 cm) with Time
BC: Al Ratio
28
26
24
22
20
18
16
14
12
10
8
6
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

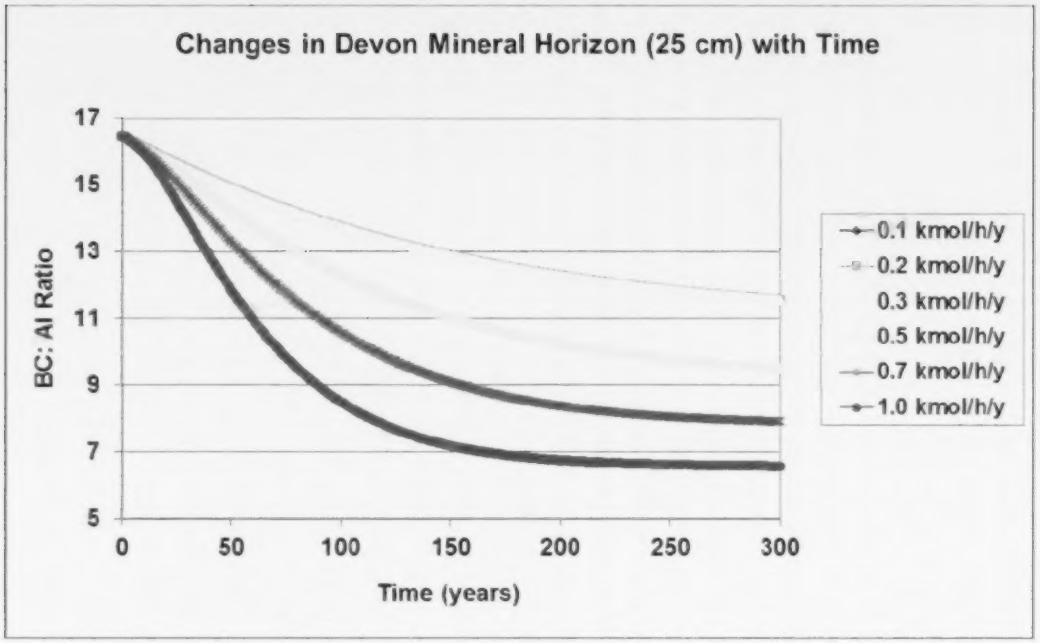

Changes in Devon LFH with Time
pH (CaCl2)
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

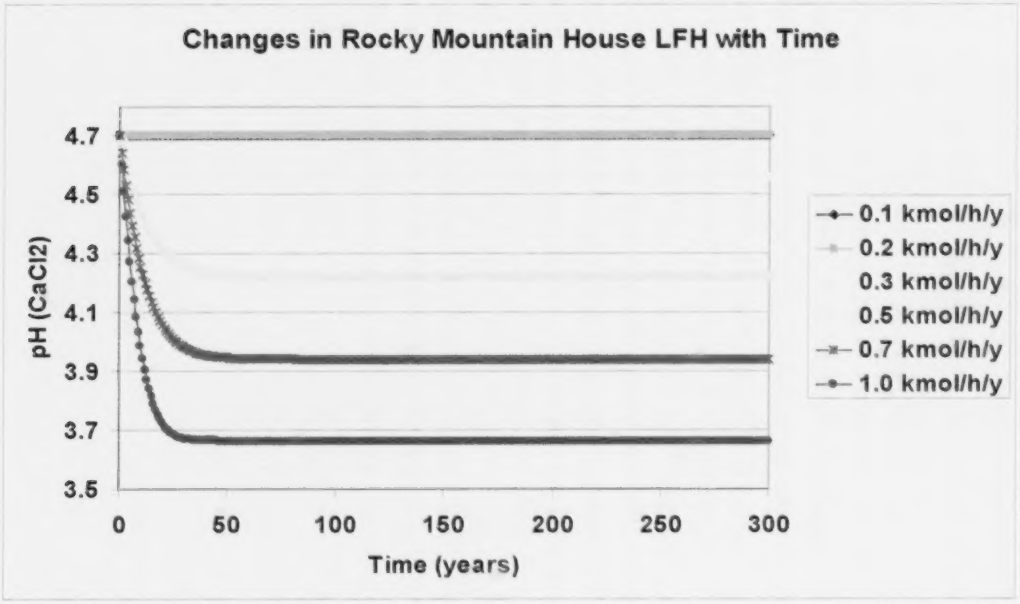

Changes in Devon LFH with Time
Base Saturation
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

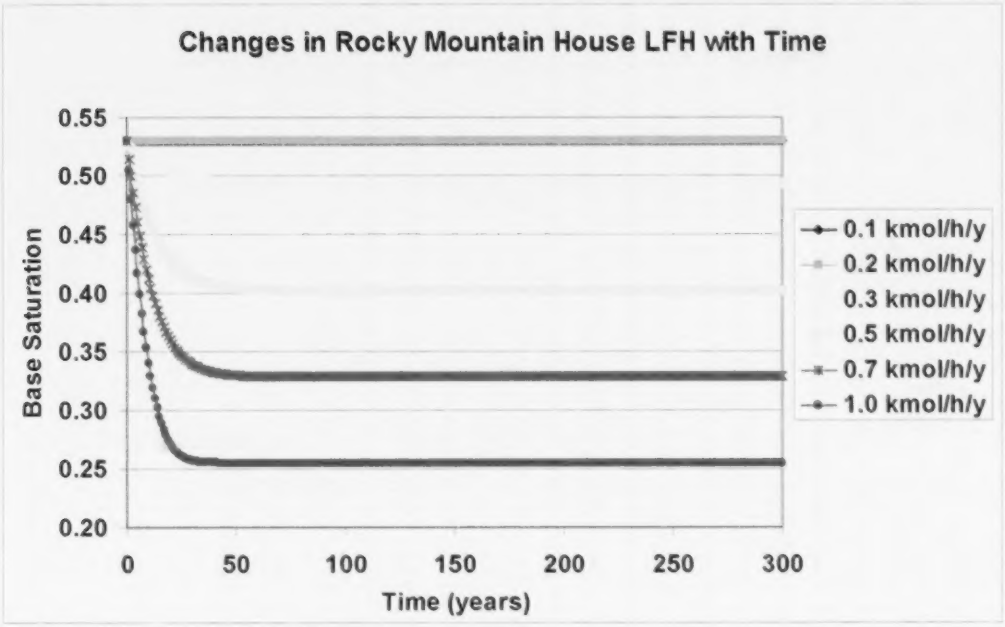

Changes in Devon LFH with Time
BC: Al Ratio
35
30
25
20
15
10
5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

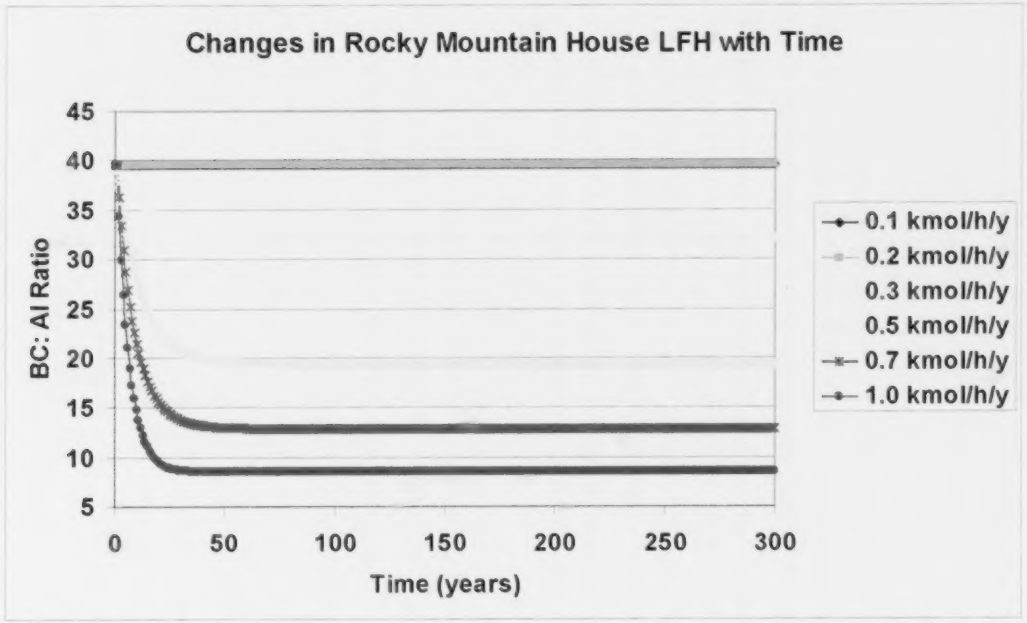

Changes in Devon Mineral Horizon (25 cm) with Time
pH (CaCl2)
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

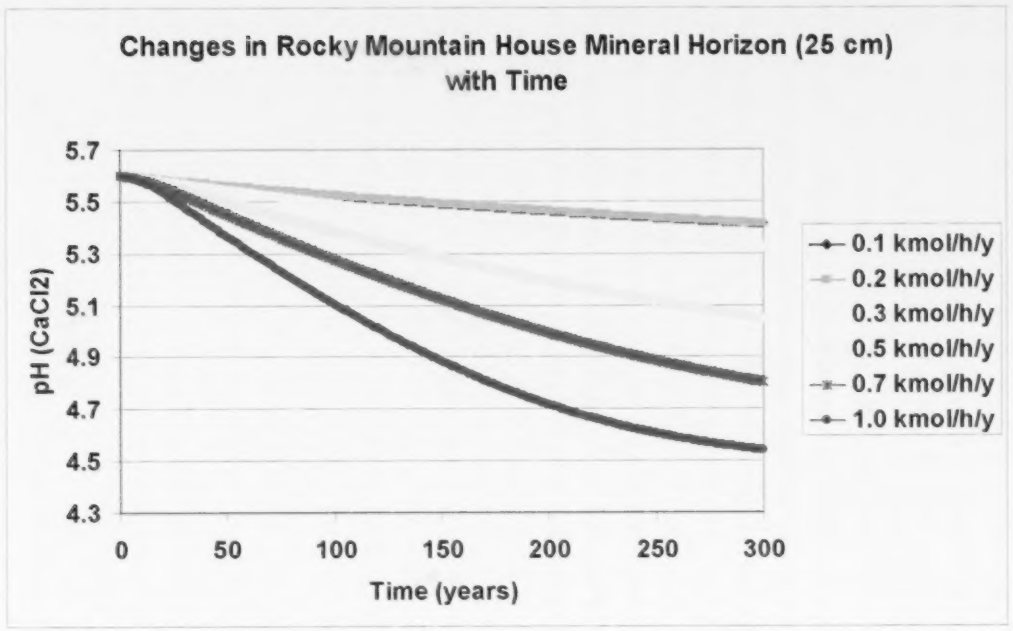

Changes in Devon Mineral Horizon (25 cm) with Time
Base Saturation
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

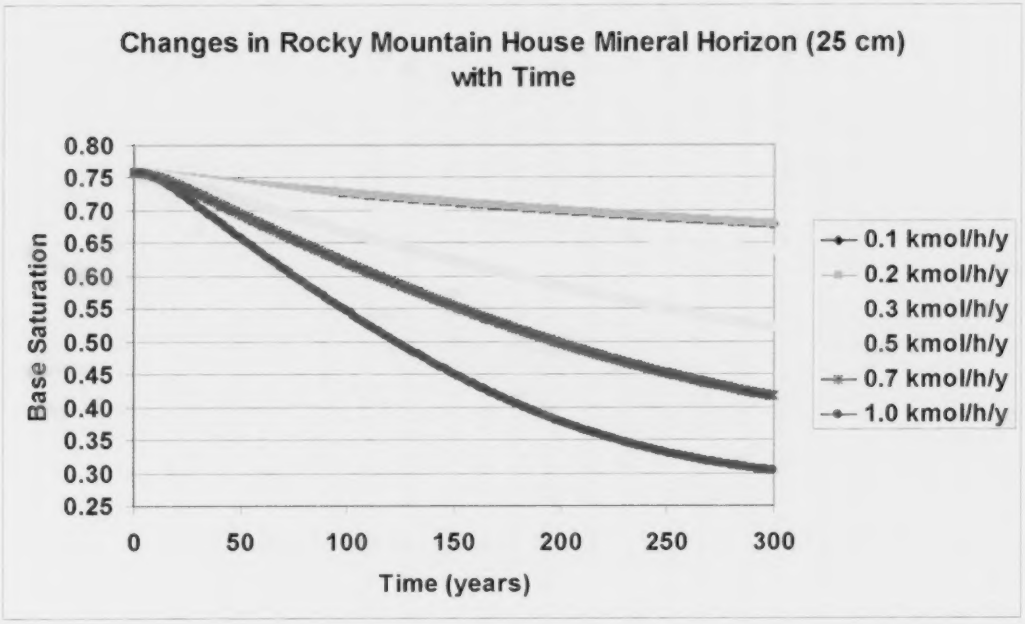

Changes in Devon Mineral Horizon (25 cm) with Time
BC: Al Ratio
17
15
13
11
9
7
5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

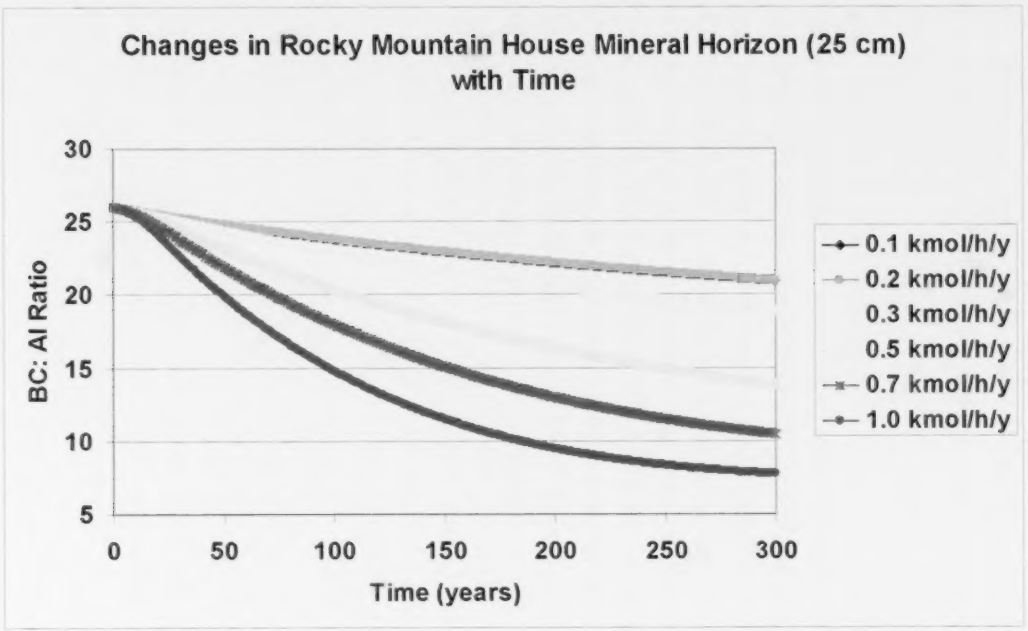

Changes in Rocky Mountain House LFH with Time
pH (CaCl2)
4.7
4.5
4.3
4.1
3.9
3.7
3.5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

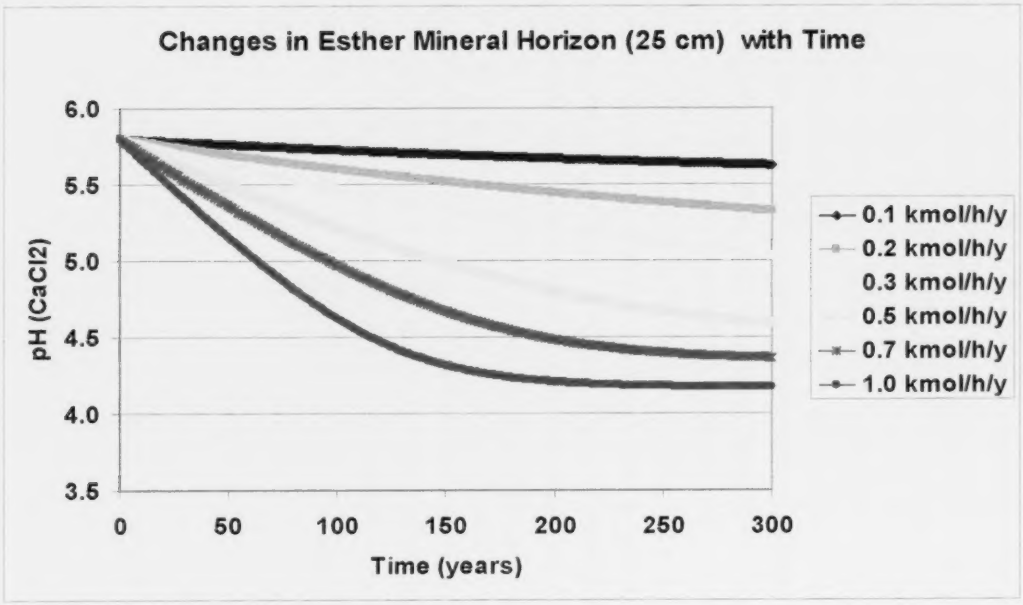

Changes in Rocky Mountain House LFH with Time
Base Saturation
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

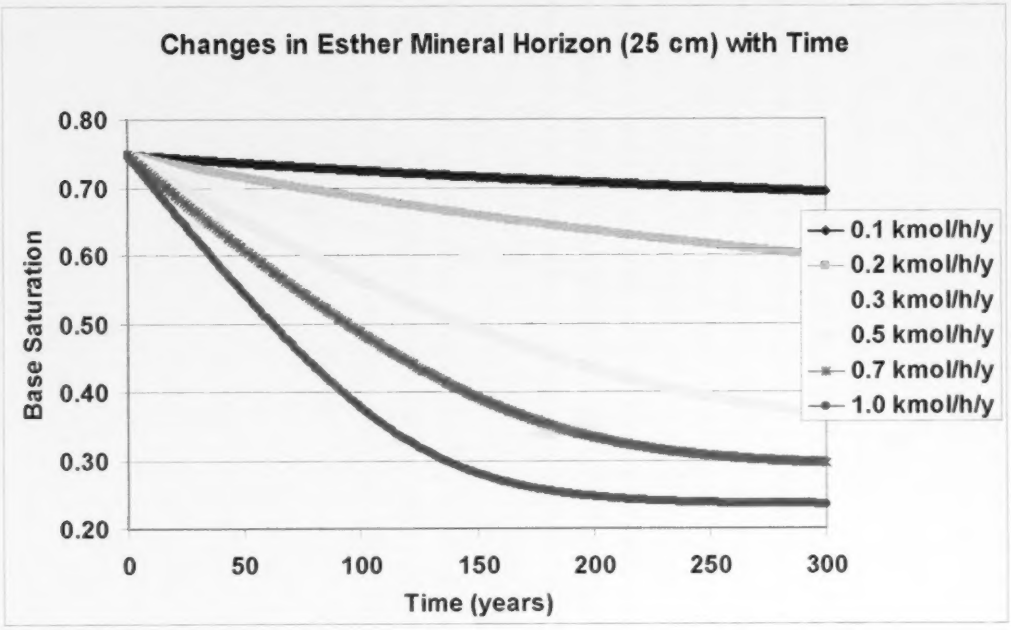

Changes in Rocky Mountain House LFH with Time
BC: Al Ratio
45
40
35
30
25
20
15
10
5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

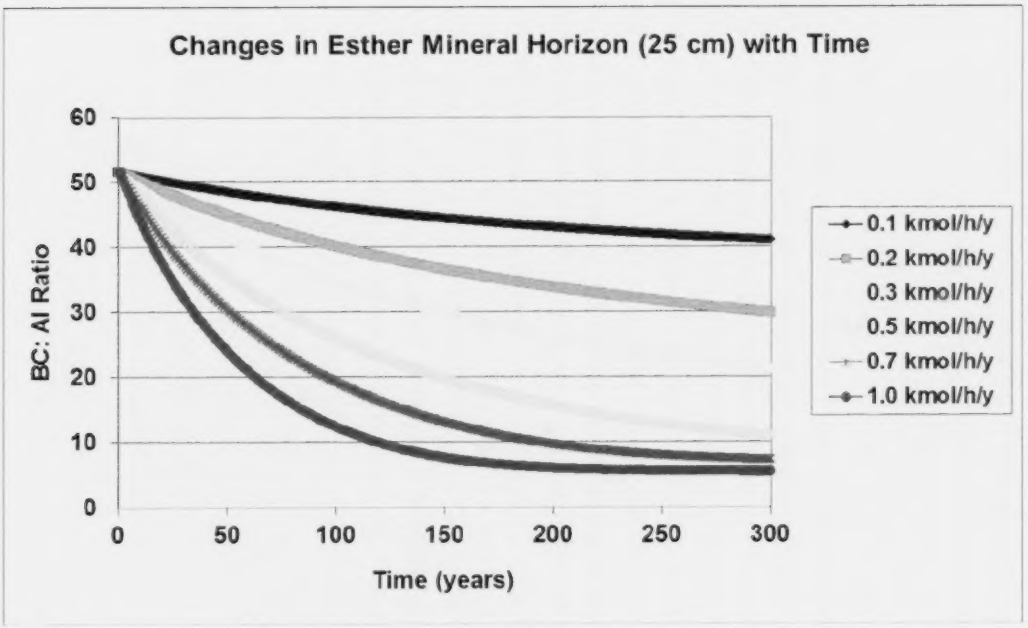

Changes in Rocky Mountain House Mineral Horizon (25 cm) with Time
pH (CaCl2)
5.7
5.5
5.3
5.1
4.9
4.7
4.5
4.3
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

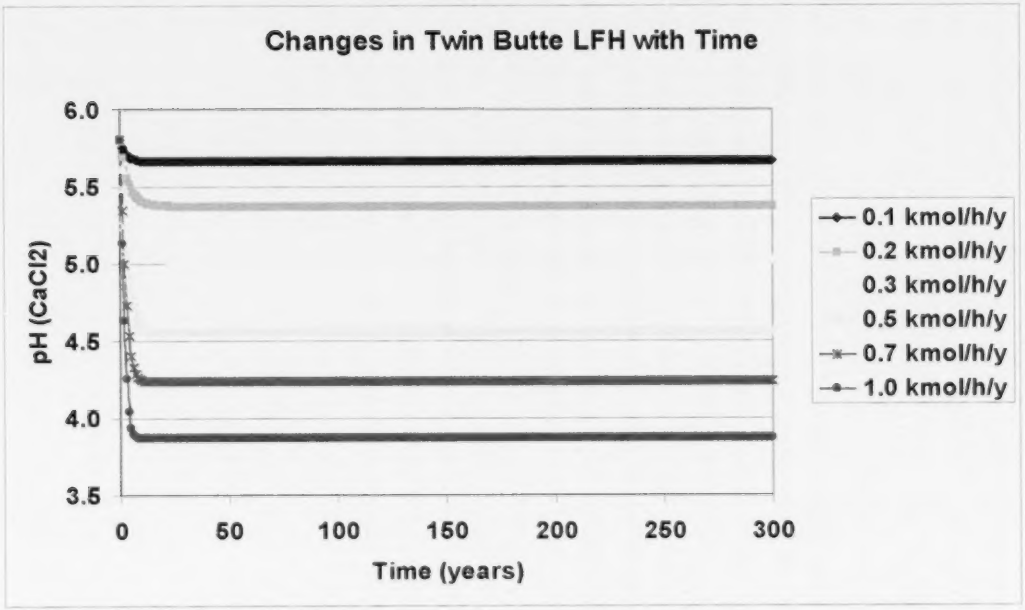

Changes in Rocky Mountain House Mineral Horizon (25 cm) with Time
Base Saturation
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

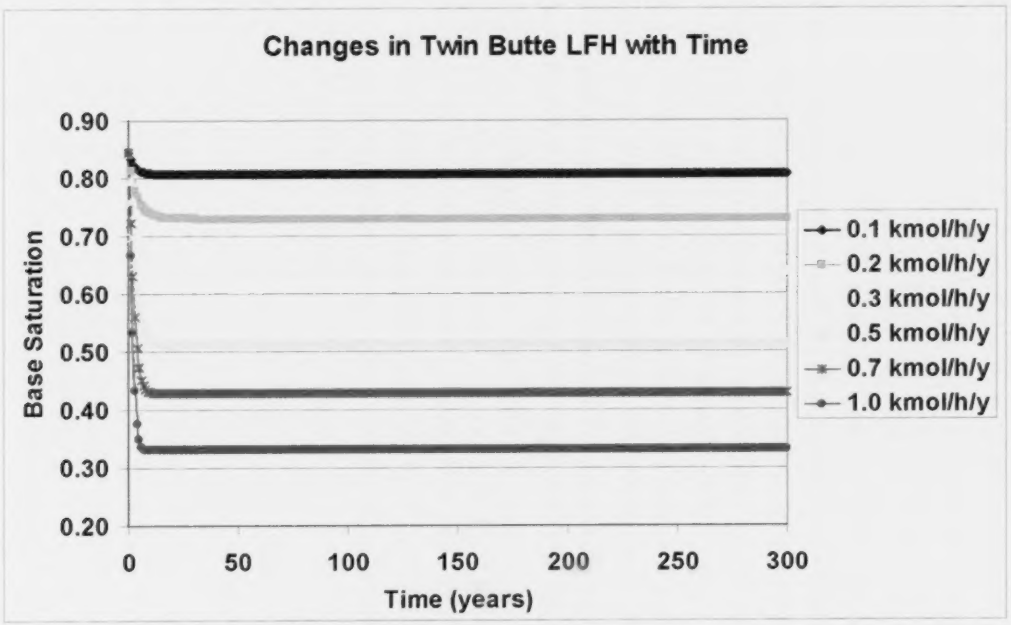

Changes in Rocky Mountain House Mineral Horizon (25 cm) with Time
BC: Al Ratio
30
25
20
15
10
5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

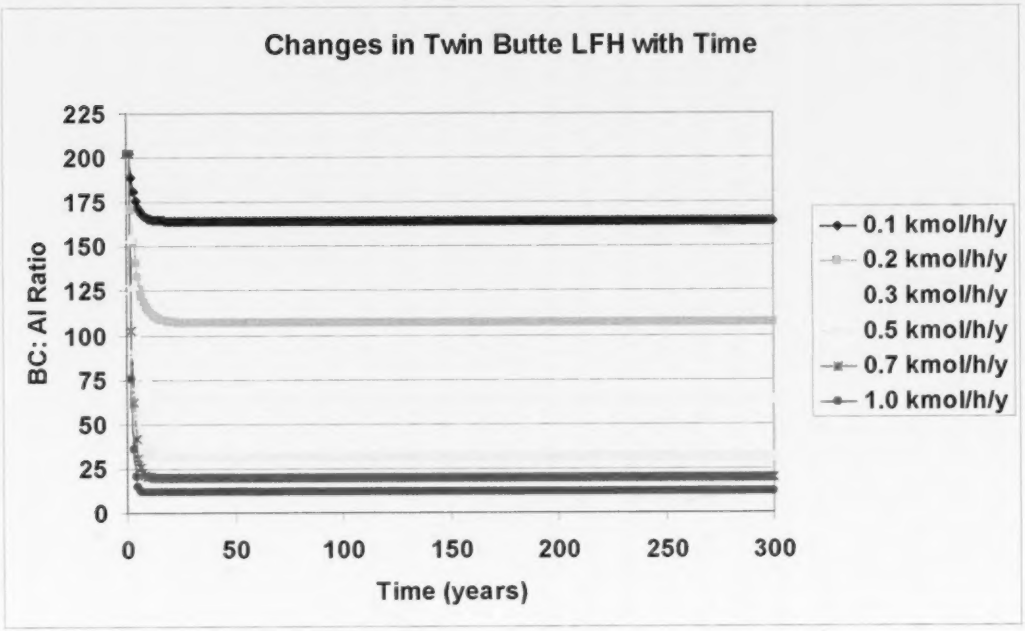

Changes in Esther Mineral Horizon (25 cm) with Time
pH (CaCl2)
6.0
5.5
5.0
4.5
4.0
3.5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

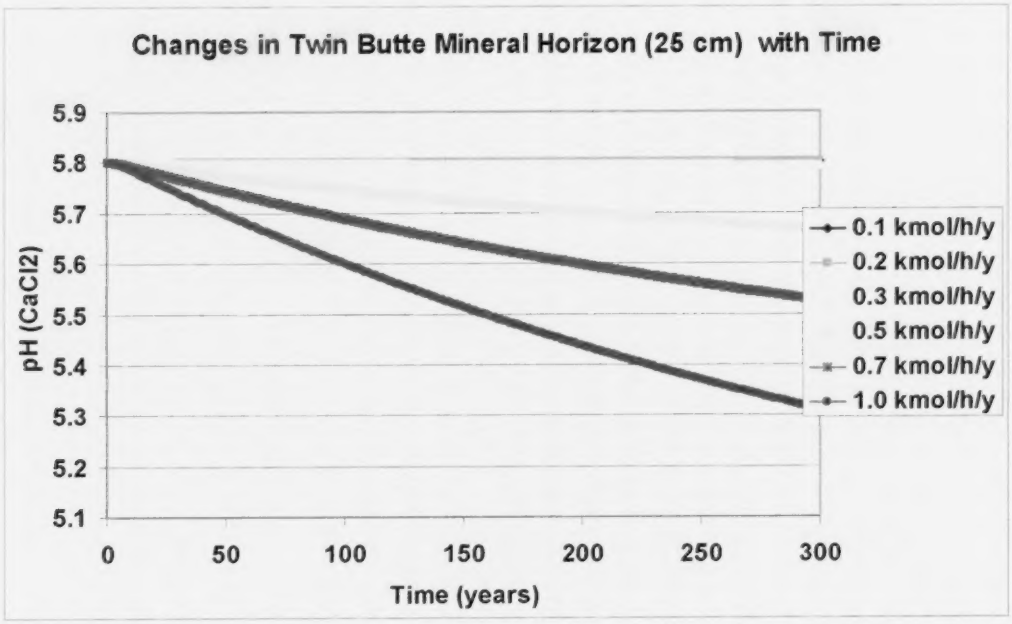

Changes in Esther Mineral Horizon (25 cm) with Time
Base Saturation
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

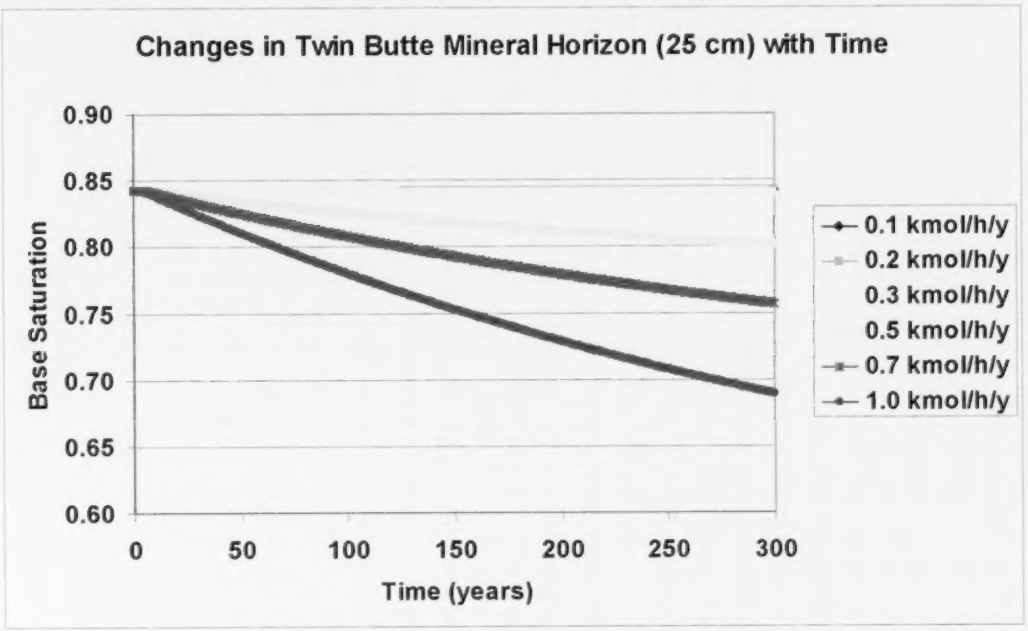

Changes in Esther Mineral Horizon (25 cm) with Time
BC: Al Ratio
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

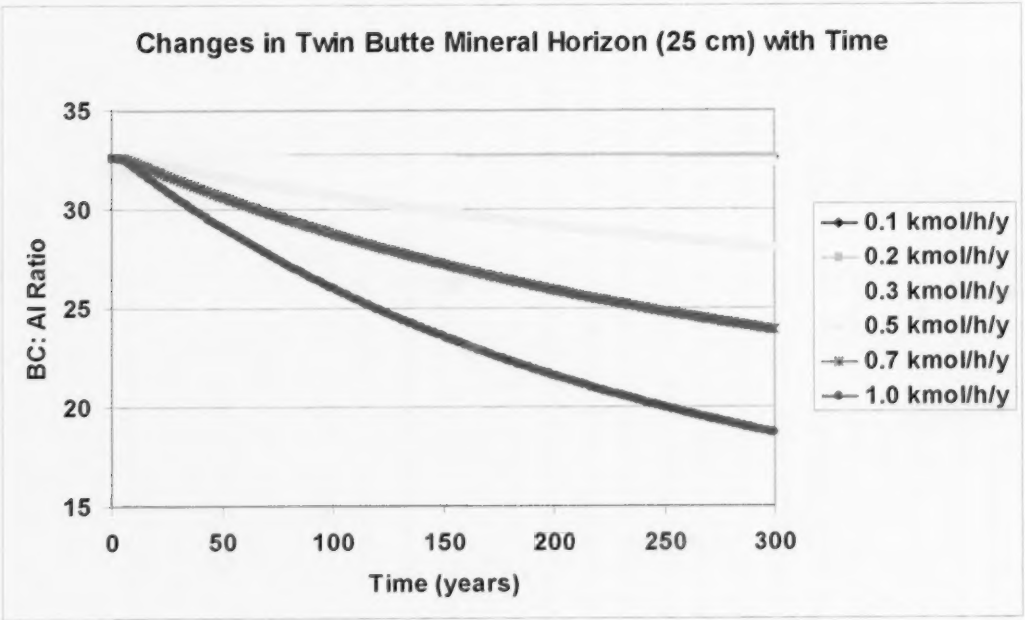

Changes in Twin Butte LFH with Time
pH (CaCl2)
6.0
5.5
5.0
4.5
4.0
3.5
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y


Changes in Twin Butte LFH with Time
Base Saturation
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y


Changes in Twin Butte LFH with Time
BC: Al Ratio
225
200
175
150
125
100
75
50
25
0
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y


Changes in Twin Butte Mineral Horizon (25 cm) with Time
pH (CaCl2)
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y


Changes in Twin Butte Mineral Horizon (25 cm) with Time
Base Saturation
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y


Changes in Twin Butte Mineral Horizon (25 cm) with Time
BC: Al Ratio
35
30
25
20
15
0
50
100
150
200
250
300
Time (years)
0.1 kmol/h/y
0.2 kmol/h/y
0.3 kmol/h/y
0.5 kmol/h/y
0.7 kmol/h/y
1.0 kmol/h/y

APPENDIX E

ANALYTICAL DATA FOR COMPOSITE SAMPLES FROM THE INITIAL SAMPLING EVENT AT EACH LONG TERM MONITORING SITE

PROCEDURES

Soil chemistry data inputs for the ARC model consist of pH_C, cation exchange capacity, base cation amounts, and base saturation percentage. pH_C and exchange cation parameters by the unbuffered $BaCl_2$ method are routinely determined as part of the analytical protocol for monitoring site samples. The ARC model uses algorithms that relate characteristics such as base saturation percentage to pH. These had been determined in earlier work (Abboud and Turchenek, 1988, 1990; Abboud et al., 2002; Turchenek and Abboud, 2001) using data from soil survey reports, which most commonly use the buffered ammonium acetate (NH_4OAc) method to determine cation exchange capacity, exchangeable bases contents, and base saturation percentage. Consequently, the $BaCl_2$ exchange parameters could not be applied for modelling purposes, and samples were re-analyzed by the NH_4OAc method in order to obtain the required data. The main features of the approach to acquiring the data are as follows:

- Composite samples were made for the re-analysis using archived samples from the initial sampling event for each site. This was done in order to reduce the number of samples for analysis, such that one sample per layer rather than twelve replicates of each layer were analyzed. The composite samples were made for each of the LFH, 0-2 cm, 2-5 cm, 5-15 cm, and 15-30 layers. A single sample was made from the replicates of each layer by measuring 2 g of LFH material or 5 g of mineral material, and then mixing each composite sample thoroughly.

- Cation exchange capacity and exchangeable cations of each sample were measured by the buffered ammonium acetate method according to Rhoades (1982).

- pH_C was determined as part of the monitoring analytical protocol, and data were therefore already available for modelling. However, pH_C was determined again on the composite samples in order to test the reproducibility of measurement on archived samples.

- As with pH_C, the measurement of exchangeable cations was theoretically not necessary, because similar levels should be obtained by use of different extractants. However, differences are commonly found, with unbuffered salt solutions such as $BaCl_2$ generally extracting larger amounts of cations as compared to NH_4OAc. Exchangeable cations were therefore determined as part of the re-analysis in order to compare extraction levels.

- Results of cation exchange capacity and exchangeable cations measurements were calculated in terms of quantities in a hectare to a 25 cm depth, as required by the model. The base saturation was calculated as ratio of base cations to the cation exchange capacity.

- The historical $BaCl_2$ exchangeable cations were similarly calculated.

- All parameters were then re-calculated using base cation levels from the historical $BaCl_2$ analyses and the cation exchange capacity from the re-analysis using the NH_4OAc extractant.

- Number of samples used to make composites (listed to indicate some missing values), and data for acidification parameters are presented in the tables below.

NUMBER OF SAMPLES USED TO MAKE THE COMPOSITES

Year Sampled	Site	LFH [z]	0-2 (cm)	2-5 (cm)	5-10 (cm)	10-15 (cm)	15-30 (cm)
1981	Fort McMurray	12	12	12	12	12	12
1982	Cold Lake	12	12	12	12	12	12
1983	High Prairie	12	12	11	12	11	11
1984	Bruderheim	10	11	9	9	8	9
2008	Fort Saskatchewan	12	12	12	12	12	12
1984	Devon	11	11	11	10	10	9
1983	Esther	[y]	12	12	12	12	12
1981	Rocky Mountain House	12	11	11	12	12	12
1982	Twin Butte	12	12	12	12	12	12

[z] LFH Layer - 2 g from each sample was used to make the composite
All other layers - 5 g from each sample was used to make the composite
[y] Esther - does not have an LFH layer

ANALYTICAL DATA FOR COMPOSITE SAMPLES

Fort McMurray Site - Sampled 1981

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1982

Sub-Site	Depth (cm)	Thickness (cm)	BD (Mg m^{-3})	pH_c	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					(kmol ha^{-1})							(kmol ha^{-1})	
North	LFH	2	0.1	3.6	8.68	1.37	0.05	1.38	55.6	11.5	0.21	2.30	11.1
	0-2	2	1.16	4.2	0.92	0.07	<0.01	0.06	4.3	1.1	0.25	2.44	10.0
	2-5	3	1.28	4.6	0.57	0.05	<0.01	0.04	2.4	0.7	0.27	2.51	9.2
	5-10	5	1.32	4.5	0.34	0.04	<0.01	0.03	2.0	0.4	0.20	2.67	13.4
	10-15	5	1.36	4.5	0.27	0.03	<0.01	0.02	2.1	0.3	0.15	2.16	14.1
	15-30	10	1.41	4.8	0.22	0.03	<0.01	0.02	1.6	0.3	0.18	3.86	21.9
Average pH($CaCl_2$) measured in 2005, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	3.6	8.68	1.37	0.05	1.38	55.6	11.5	0.21	2.30	11.1
			0-25 cm	4.6	0.35	0.04	0.005	0.03	2.1	0.42	0.19	13.6	68.6
Average pH($CaCl_2$) measured in 1981, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 1981 $BaCl_2$ Exchangeable Cations			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	4.6	0.30	0.03	0.004	0.02	2.1	0.33	0.22	15.3	69
Data Applied in the ARC Model			LFH	3.6							0.21	2.3	11.1
			0-25 cm	4.6							0.22	15.3	68.6

Cold Lake Site - Sampled 1982

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1982

Sub-Site	Depth (cm)	Thickness (cm)	BD (Mg m^{-3})	pH_c	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					(kmol ha^{-1})							(kmol ha^{-1})	
East	LFH	2	0.1	4.4	21.2	4.72	<0.01	1.51	61.8	27.4	0.44	5.48	12.4
	0-2	2	1.23	4.9	2.56	0.34	<0.01	0.08	5.3	3.0	0.56	7.3	13.0
	2-5	3	1.36	4.8	1.11	0.16	0.01	0.04	2.5	1.3	0.52	5.4	10.4
	5-10	5	1.39	4.6	0.71	0.13	0.01	0.04	1.9	0.9	0.47	6.1	13.1
	10-15	5	1.43	4.6	0.64	0.13	0.01	0.06	2.6	0.8	0.32	6.0	18.5
	15-30	10	1.49	4.9	0.58	0.09	0.01	0.06	2.5	0.7	0.29	10.9	37.9
Average pH($CaCl_2$) measured in 2005, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	4.4	21.2	4.72	<0.01	1.51	61.8	27.4	0.44	5.48	12.4
			0-25 cm	4.8	0.84	0.13	0.007	0.05	2.64	1.0	0.38	36.0	93
Average pH($CaCl_2$) measured in 1982, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 1982 $BaCl_2$ Exchangeable Cations			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	4.8	0.78	0.13	0.003	0.05	2.64	0.9	0.35	32.8	93
Data Applied in the ARC Model			LFH	4.4							0.44	5.5	12.4
			0-25 cm	4.8							0.35	32.8	93

ANALYTICAL DATA FOR COMPOSITE SAMPLES

High Prairie Site - Sampled 1983

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1983

Sub-Site	Depth (cm)	Thickness (cm)	BD ($Mg\ m^{-3}$)	pH_C	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					($kmol\ ha^{-1}$)							($kmol\ ha^{-1}$)	
East	LFH	2	0.1	4.1	15.9	2.81	<0.01	1.71	59.2	20.5	0.35	4.1	11.8
	0-2	2	1.2	5.0	2.42	0.17	<0.01	0.08	6.5	2.7	0.41	6.4	15.6
	2-5	3	1.27	5.2	1.79	0.13	<0.01	0.07	4.7	2.0	0.43	7.6	17.8
	5-10	5	1.37	5.1	1.00	0.09	<0.01	0.05	3.2	1.1	0.36	7.8	21.6
	10-15	5	1.42	4.9	0.67	0.08	<0.01	0.04	2.6	0.8	0.30	5.6	18.7
	15-30	10	1.47	4.8	0.53	0.08	<0.01	0.03	2.5	0.6	0.26	9.4	36.0
Average pH($CaCl_2$) measured in 2005, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	4.1	15.9	2.81	<0.01	1.71	59.2	20.5	0.35	4.1	11.8
			0-25 cm	4.9	0.96	0.09	0.01	0.04	3.22	1.09	0.32	36.8	110
Average pH($CaCl_2$) measured in 1983, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 193 $BaCl_2$ Exchangeable Cations			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	5.0							0.35	38.8	110
Data Applied in the ARC Model			LFH	4.1							0.35	4.1	11.8
			0-25 cm	4.9							0.35	38.8	110

Bruderheim Site - Sampled 1984

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1984

Sub-Site	Depth (cm)	Thickness (cm)	BD ($Mg\ m^{-3}$)	pH_C	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					($kmol\ ha^{-1}$)							($kmol\ ha^{-1}$)	
West	LFH	2	0.14	4.0	15.4	3.34	0.10	2.01	58.8	20.9	0.35	5.8	16.5
	0-2	2	1.04	4.6	4.38	0.49	0.01	0.16	11.4	5.0	0.44	10.5	23.6
	2-5	3	1.21	4.8	2.68	0.31	0.01	0.09	6.2	3.1	0.50	11.3	22.6
	5-10	5	1.32	4.7	1.44	0.25	0.01	0.07	4.0	1.8	0.45	11.8	26.1
	10-15	5	1.40	4.6	1.11	0.25	0.01	0.07	3.3	1.4	0.44	10.1	22.8
	15-30	10	1.42	4.8	1.14	0.27	0.01	0.08	2.8	1.5	0.53	21.4	40.2
Average pH($CaCl_2$) measured in 2010, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	4.0	15.4	3.34	0.10	2.01	58.8	20.9	0.35	5.8	16.5
			0-25 cm	4.72	1.64	0.29	0.01	0.09	4.23	2.02	0.49	65	135
Average pH($CaCl_2$) measured in 1984, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 1984 $BaCl_2$ Exchangeable Cations			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	4.75	1.93	0.29	0.01	0.09	4.23	2.22	0.55	73.9	135
Data Applied in the ARC Model			LFH	4.0							0.35	5.8	16.5
			0-25 cm	4.7							0.55	73.9	135

ANALYTICAL DATA FOR COMPOSITE SAMPLES

Devon Site - Sampled 1984

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1984

Sub-Site	Depth (cm)	Thickness (cm)	BD (Mg m^{-3})	pH_C	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					(kmol ha^{-1})							(kmol ha^{-1})	
North	LFH	6	0.18	4.6	27.4	6.38	<0.01	1.87	70.5	35.6	0.51	38.5	76.1
	0-2	2	0.96	4.8	6.0	0.97	0.01	0.25	13.5	7.2	0.53	13.8	26.0
	2-5	3	1.17	4.9	3.7	0.66	0.01	0.17	7.8	4.5	0.58	15.8	27.5
	5-10	5	1.26	4.8	2.8	0.55	0.01	0.13	6.2	3.5	0.56	21.8	39.2
	10-15	5	1.33	4.7	2.4	0.50	0.02	0.12	5.4	3.0	0.56	20.1	35.7
	15-30	10	1.38	4.8	2.2	0.51	0.02	0.13	4.9	2.9	0.59	39	67.0
Average pH($CaCl_2$) measured in 2010, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	4.6	27.4	6.38	<0.01	1.87	70.5	35.6	0.51	38.5	76.1
			0-25 cm	4.8	2.8	0.57	0.01	0.14	6.28	3.6	0.57	111	195
Average pH($CaCl_2$) measured in 1984, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 1984 $BaCl_2$ Exchangeable Cations			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	4.9	3.7	0.64	0.01	0.15	6.28	4.33	0.71	139	195
Data Applied in the ARC Model			LFH	4.6							0.51	38.5	76.1
			0-25 cm	4.8							0.71	139	195

Rocky Mountain House Site - Sampled 1981

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1981

Sub-Site	Depth (cm)	Thickness (cm)	BD (Mg m^{-3})	pH_C	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					(kmol ha^{-1})							(kmol ha^{-1})	
West	LFH	4	0.1	4.7	29.0	7.96	<0.01	2.37	74.0	39.3	0.53	15.7	29.6
	0-2	2	1.24	5.2	4.12	1.03	<0.01	0.31	9.4	5.5	0.58	13.6	23.4
	2-5	3	1.36	5.1	3.31	0.85	0.01	0.30	7.9	4.5	0.57	18.3	32.1
	5-10	5	1.43	5.0	3.20	0.90	0.01	0.25	8.0	4.4	0.54	31.2	57.3
	10-15	5	1.47	5.1	3.64	1.11	0.01	0.20	8.3	4.9	0.60	36	61.0
	15-30	10	1.49	5.3	5.29	1.75	0.01	0.20	10.9	7.2	0.66	108	163.0
Average pH($CaCl_2$) measured in 2010, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	4.7	29.0	7.96	<0.01	2.37	74.0	39.3	0.53	15.7	29.6
			0-25 cm	5.17	4.2	1.29	0.01	0.23	9.34	5.7	0.61	207	337
Average pH($CaCl_2$) measured in 1981, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 1981 $BaCl_2$ Exchangeable Cations			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	5.20	5.45	1.39	0.02	0.23	9.34	6.83	0.76	256	337
Data Applied in the ARC Model			LFH	4.7							0.53	15.7	29.6
			0-25 cm	5.2							0.76	256	337

ANALYTICAL DATA FOR COMPOSITE SAMPLES

Esther Site - Sampled 1983

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1983

Sub-Site	Depth (cm)	Thickness (cm)	BD (Mg m^{-3})	pH_C	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					(kmol ha^{-1})							(kmol ha^{-1})	
North	0-2	2	1.21	5.4	3.87	0.94	0.01	0.45	8.0	5.3	0.66	12.7	19.4
	2-5	3	1.37	5.6	3.20	0.70	0.01	0.31	6.1	4.2	0.69	17.4	25.2
	5-10	5	1.45	5.6	3.31	0.67	0.02	0.20	6.4	4.2	0.66	30	46.1
	10-15	5	1.52	5.5	2.97	0.61	<0.01	0.13	5.6	3.7	0.67	28.3	42.3
	15-30	10	1.56	5.6	3.07	0.78	0.02	0.11	5.7	4.0	0.70	62.0	89.0
Average pH($CaCl_2$) measured in 2010, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	5.6	3.18	0.73	0.01	0.18	6.04	4.1	0.68	151	222
Average pH($CaCl_2$) measured in 1983, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 1983 $BaCl_2$ Exchangeable Cations			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	5.8	3.64	0.72	0.01	0.16	6.04	4.36	0.75	166	222
Data Applied in the ARC Model			LFH	-	-	-	-	-	-	-	-	-	-
			0-25 cm	5.8							0.75	166	222

Twin Butte Site - Sampled 1982

pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 1982

Sub-Site	Depth (cm)	Thickness (cm)	BD (Mg m^{-3})	pH_C	Ca	Mg	Na	K	CEC	Base Cations	BSat	Base Cations	CEC
					(kmol ha^{-1})							(kmol ha^{-1})	
West	LFH	1	0.1	5.8	32.1	9.05	0.03	5.08	54.5	46.2	0.85	4.6	5.45
	0-2	2	0.63	5.7	26.8	6.37	<0.01	4.06	58.0	37.2	0.64	46.9	73.1
	2-5	3	0.86	5.4	20.5	4.38	<0.01	2.65	44.4	27.5	0.62	71	114.5
	5-10	5	0.99	5.3	16.8	3.60	<0.01	1.97	38.4	22.4	0.58	111	190.2
	10-15	5	1.04	5.4	15.1	3.47	<0.01	1.57	35.3	20.1	0.57	105	183.6
	15-30	10	1.16	5.5	13.1	3.49	<0.01	1.19	31.1	17.8	0.57	207	360.9
Average pH($CaCl_2$) measured in 2010, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only			LFH	5.8	32.1	9.05	0.03	5.08	54.5	46.2	0.85	4.6	5.45
			0-25 cm	5.44	16.2	3.84	0.01	1.83	37.2	21.9	0.59	540	922
Average pH($CaCl_2$) measured in 1982, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 1982 $BaCl_2$ Exchangeable Cations			LFH										
			0-25 cm	5.55	25.3	4.83	0.02	1.40	37.2	30.2	0.84	777	922
Data Applied in the ARC Model			LFH	5.8							0.85	4.6	5.45
			0-25 cm	5.4							0.84	777	922

ANALYTICAL DATA FOR COMPOSITE SAMPLES

Fort Saskatchewan Site - Sampled 2008													
pH and Ammonium Acetate (pH7) Exchangeable Parameters Measured 2008													
Sub-Site	**Depth (cm)**	**Thickness (cm)**	**BD ($Mg\ m^{-3}$)**	**pH_c**	**Ca**	**Mg**	**Na**	**K**	**CEC**	**Base Cations**	**BSat**	**Base Cations**	**CEC**
					($kmol\ ha^{-1}$)							($kmol\ ha^{-1}$)	
North	LFH	3	0.10	4.7	36.3	5.81	0.05	2.03	65.3	44.2	0.68	13.2	19.6
	0-2	2	1.45	4.7	8.66	1.13	0.02	0.34	15.4	10.2	0.66	29.4	44.8
	2-5	3	1.45	4.6	2.95	0.41	0.02	0.13	7.0	3.5	0.51	15.3	30.3
	5-10	5	1.45	4.7	2.07	0.32	0.01	0.11	5.1	2.5	0.50	18.2	36.7
	10-15	5	1.45	4.7	1.73	0.31	0.01	0.10	4.1	2.1	0.53	15.6	29.5
	15-30	10	1.50	5.1	1.98	0.40	0.02	0.10	3.6	2.5	0.70	37.4	53.7
South	LFH	2.5	0.10	4.9	20.6	3.49	0.02	1.18	38.3	25.2	0.66	6.3	9.6
	0-2	2	1.45	4.9	5.90	0.80	0.01	0.25	9.9	7.0	0.71	20.2	28.7
	2-5	3	1.45	4.9	2.59	0.41	0.01	0.13	5.2	3.1	0.61	13.7	22.6
	5-10	5	1.45	4.9	2.25	0.37	0.01	0.11	4.7	2.7	0.58	19.9	34.3
	10-15	5	1.45	4.9	2.04	0.35	0.01	0.10	4.0	2.5	0.64	18.2	28.7
	15-30	10	1.50	5.4	2.24	0.43	0.02	0.09	3.5	2.8	0.79	41.5	52.5
Average pH($CaCl_2$) measured 2010, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate Extraction Only		LFH		4.8	28.4	4.7	0.04	1.6	51.8	34.7	0.67	9.7	14.6
		0-25 cm		4.9	2.6	0.4	0.01	0.1	4.94	3.13	0.64	116.2	180.9
Average pH($CaCl_2$) measured 2008, and Average 0-25 cm Exchangeable Parameters Based on Ammonium Acetate CEC and 2008 $BaCl_2$ Exchangeable Cations		LFH		4.7	24.3	4.5	0.5	1.4		30.7	0.63	9.2	14.6
		0-25 cm		4.8	1.5	0.3	1.4	0.3		3.40	0.65	117.9	180.9
Data Applied in the ARC Model		LFH		4.8							0.67	9.7	14.6
		0-25 cm		4.9							0.64	116.2	180.9

APPENDIX F. FORT SASKATCHEWAN SITE INFORMATION

The Fort Saskatchewan site was added to the Long Term Soil Acidification Monitoring Program in 2008 (rational for the addition of this site is provided in Section 1- Introduction). In addition to monitoring data, additional information was collected during the first sampling as part of baseline characterization of the site. A description of the typical soil profile at the site is presented in Appendix A. The plot layout for this site is included with those of other sites in Appendix B. The following tables present the chemistry information for the site.

Fort Saskatchewan Site: pH, Carbon, Nitrogen, Sulphur, Nutrients and Cation Exchange Properties

Depth	Soil pH	Soil pH	Total Soil Content (%)			Extractable Nutrients (mg kg^{-1})			Exchangeable Cations (cmol(+)kg^{-1})							CEC	Base Sat.
(cm)	(H_2O)	($CaCl_2$)	Carbon	Nitrogen	Sulphur	(NO_3+NO_2)-N	NH4-N	PO_4-P	Na	K	Ca	Mg	Al	Fe	Mn	(cmol(+) kg^{-1})	(%)
North Site																	
LFH	5.1	4.8	17.8	0.7	0.085	10.1	35.1	58.7	0.5	1.4	24.3	4.5	0.10	0.02	1.3	32.1	95
cv	7	7	32	38	47	88	94	23	40	38	35	42	108	48	48	33	3
0-2	5.1	4.6	4.0	0.2	0.020	1.1	5.0	18.1	0.3	0.3	7.5	1.0	0.3	0.02	0.4	9.9	92
cv	10	11	49	54	60	37	34	26	58	40	43	49	89	41	61	39	7
2-5	5.1	4.4	1.3	0.07	0.004	0.7	2.1	24.7	0.3	0.1	2.9	0.4	0.4	0.01	0.2	4.3	84
cv	7	7	28	10	43	33	21	49	40	39	35	26	65	42	44	21	12
5-10	5.1	4.5	0.7	0.06	0.001	0.5	1.7	26.6	0.3	0.1	2.0	0.3	0.4	0.01	0.1	3.3	83
cv	5	5	27	19	35	41	18	36	20	48	32	25	54	73	45	17	12
10-15	5.2	4.5	0.4	0.06	0.001	0.5	1.4	26.0	0.3	0.1	1.7	0.3	0.3	0.01	0.06	2.8	85
cv	4	4	31	10	36	29	25	21	28	44	16	25	43	63	56	8	8
15-30	5.6	4.9	0.2	0.05	0.001	0.6	1.2	24.3	0.2	0.1	2.0	0.4	0.10	0.01	0.03	2.9	96
cv	3	3	42	8	0	29	5	24	31	42	12	21	52	30	54	7	2
30-45	5.8	5.1	0.2	0.05	<0.001	0.6	<1.0	21.2	0.3	0.1	2.0	0.4	0.06	0.01	0.02	2.9	97
cv	3	3	27	10	-	39	-	17	33	42	8	11	45	41	42	3	2
45-60	5.9	5.2	0.2	0.06	0.00	0.6	<1.0	22.7	0.3	0.1	2.1	0.4	0.06	0.01	0.02	2.9	97
cv	3	3	21	7	0	51	-	9	32	32	11	16	32	28	34	7	1

Abbreviations: CEC – cation exchange capacity; cv – coefficient of variation

Fort Saskatchewan Site: pH, Carbon, Nitrogen, Sulphur, Nutrients and Cation Exchange Properties

Depth	Soil pH	Soil pH	Total Soil Content (%)			Extractable Nutrients (mg kg-1)			Exchangeable Cations (cmol(+) kg-1)							CEC	Base Sat.
(cm)	(H_2O)	($CaCl_2$)	Carbon	Nitrogen	Sulphur	(NO_3+NO_2)-N	NH_4-N	PO4-P	Na	K	Ca	Mg	Al	Fe	Mn	(cmol(+) kg^{-1})	(%)
South Sub-Site																	
LFH	5.2	4.9	14.5	0.55	0.060	6.4	23.2	35.1	0.6	0.9	16.7	3.0	0.11	0.02	0.88	22.2	96
cv	8	8	78	70	81	136	88	48	39	65	51	59	116	15	76	51	3
0-2	5.3	4.9	2.27	0.12	0.010	0.7	4.4	13.6	0.5	0.2	5.5	0.8	0.24	0.02	0.23	7.4	93
cv	12	13	23	30	43	55	16	29	16	15	53	32	88	78	50	40	7
2-5	5.4	4.8	0.77	0.08	0.002	0.5	2.5	20.7	0.4	0.1	2.6	0.4	0.24	0.01	0.12	4.0	91
cv	8	9	13	6	38	43	38	34	7	20	30	20	91	40	59	17	9
5-10	5.4	4.8	0.56	0.07	0.001	0.6	2.2	23.8	0.4	0.1	2.3	0.4	0.20	0.01	0.07	3.5	92
cv	6	7	22	7	57	86	35	29	5	28	20	16	77	20	44	10	6
10-15	5.4	4.8	0.36	0.07	0.001	0.5	2.2	21.8	0.4	0.1	2.0	0.4	0.17	0.01	0.04	3.1	93
cv	6	6	16	9	42	14	42	24	8	30	18	16	63	12	37	9	4
15-30	5.9	5.2	0.20	0.06	0.001	0.5	2.2	17.9	0.4	0.1	2.2	0.4	0.03	0.01	0.02	3.2	98
cv	3	3	17	8	0.0	40	13	24	6	19	8	10	61	23	45	6	1
30-45	6.0	5.3	0.18	0.07	0.001	0.6	2.1	17.3	0.4	0.1	2.2	0.5	0.02	<0.01	0.01	3.2	99
cv	3	3	15	6	0.0	32	17	21	6	12	7	11	51	-	39	6	1
45-60	6.2	5.4	0.16	0.06	0.001	0.5	2.1	17.3	0.4	0.1	2.3	0.5	0.01	<0.01	0.01	3.3	100
cv	2	2	7	4	0.0	34	4	20	7	5	6	10	24	-	22	6	0.3

Abbreviations: CEC – cation exchange capacity; cv – coefficient of variation

Fort Saskatchewan Site: Electrical Conductivity, Saturation and Soluble Ions

Depth	Saturation	Extract	EC	Soluble Ions (mg L^{-1})													
(cm)	(%)	pH	(dS m^{-1})	Na	K	Ca	Mg	Al	Fe	Mn	S	Alk.	HCO_3	Cl	NO_3-N	NO_2-N	NH_4
North Sub-Site																	
LFH	314.7	5.1	0.7	3.5	101.3	139.0	31.0	4.3	2.2	11.5	26.3	189.0	189.0	15.8	<0.5	<0.5	6.1
cv	32	7	26	29	28	41	36	64	60	37	30	66	66	33	-	-	178
0-2	79.0	5.1	0.4	5.4	32.4	83.7	15.9	5.4	3.6	8.7	17.1	91.9	91.9	9.9	<0.5	<0.5	2.2
cv	28	14	42	23	42	34	46	76	58	53	26	120	120	20	-	-	54
2-5	50.0	5.3	0.2	5.6	9.7	31.3	5.7	3.7	2.3	3.8	8.7	48.0	47.9	4.8	<0.5	<0.5	1.1
cv	8	14	28	25	47	32	37	54	57	48	30	83	83	17	-	-	97
5-10	44.9	5.6	0.1	5.6	7.4	21.6	3.7	2.8	1.6	2.4	7.2	31.9	31.9	3.7	<0.5	<0.5	<0.1
cv	8	10	17	18	54	22	26	57	61	44	26	32	32	23	-	-	-
10-15	41.7	5.6	0.1	5.8	6.0	17.8	3.0	3.4	1.9	1.5	6.2	26.7	26.7	3.1	<0.5	<0.5	<0.1
cv	7	7	11	28	48	16	20	45	47	48	30	16	16	20	-	-	-
15-30	39.6	6.2	0.1	4.8	5.5	13.9	2.7	5.0	2.9	0.4	3.9	23.7	23.7	2.6	<0.5	<0.5	<0.1
cv	6	5	27	23	54	34	40	192	186	77	41	30	30	30	-	-	-
30-45	39.2	6.5	0.1	4.5	5.8	12.0	2.7	9.9	5.6	0.2	3.0	20.6	20.6	2.7	<0.5	<0.5	<0.1
cv	7	4	22	19	50	25	44	138	136	73	31	32	32	58	-	-	-
45-60	38.6	6.5	0.1	4.5	5.8	11.3	2.4	8.1	4.6	0.3	2.9	21.1	21.1	3.0	<0.5	<0.5	<0.1
cv	5	4	20	21	44	25	34	124	122	49	35	20	20	39	-	-	-

Abbreviations: EC –Electrical conductivity; Alk. – alkalinity; cv – coefficient of variation

Fort Saskatchewan Site: Electrical Conductivity, Saturation and Soluble Ions

Depth	Saturation	Extract	EC	Soluble Ions (mg L^{-1})													
(cm)	(%)	pH	(dS m^{-1})	Na	K	Ca	Mg	Al	Fe	Mn	S	Alk.	HCO_3	Cl	NO_3-N	NO_2-N	NH_4
South Site																	
LFH	317	5.2	0.6	3.4	77.9	104.3	23.3	4.1	2.2	8.4	22.3	138.6	138.6	11.8	<0.5	<0.5	2.7
cv	58	7	13	16	19	21	26	49	56	32	13	55	55	19	-	-	144
0-2	64	5.5	0.4	5.0	24.5	73.7	13.3	5.0	3.4	6.2	14.1	100.2	100.2	7.5	<0.5	<0.5	1.5
cv	11	13	31	20	20	41	27	83	78	60	25	71	71	36	-	-	64
2-5	46	5.8	0.2	4.8	10.4	31.5	5.7	3.9	2.2	2.6	7.4	54.8	54.8	4.3	<0.5	<0.5	0.4
cv	5	11	27	12	25	40	29	53	51	37	28	57	57	20	-	-	20
5-10	44	6.0	0.2	5.1	8.6	23.2	4.2	4.2	2.4	1.3	6.0	42.3	42.3	4.7	<0.5	<0.5	<0.1
cv	5	9	20	9	38	33	26	59	62	58	26	56	56	50	-	-	-
10-15	41	6.0	0.1	4.9	6.7	20.2	3.5	4.5	2.5	0.8	5.5	38.0	38.0	3.7	<0.5	<0.5	<0.1
cv	4	7	18	10	39	29	20	58	61	56	29	42	42	28	-	-	-
15-30	40	6.6	0.1	4.3	6.0	12.8	3.5	17.9	10.5	0.2	3.3	24.3	24.3	2.9	<0.5	<0.5	<0.1
cv	2	3	20	12	30	22	21	55	54	34	30	25	25	41	-	-	-
30-45	39	6.7	0.1	4.4	6.1	10.4	3.7	23.8	14.0	0.1	2.7	20.5	20.5	3.1	<0.5	<0.5	<0.1
cv	1	3	16	14	33	17	26	48	48	13	23	22	22	36	-	-	-
45-60	40	6.8	0.1	4.5	5.8	9.5	3.9	27.6	16.2	0.1	2.6	15.2	15.2	2.7	<0.5	<0.5	<0.1
cv	2	2	12	12	26	15	31	43	42	28	29	34	34	21	-	-	-

Abbreviations: EC –Electrical conductivity; Alk. – alkalinity; cv – coefficient of variation